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Understanding the mechanism for response selection in compatibility tasks: Referential coding contrasted with biological properties of the hands

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UNDERSTANDING THE MECHANISM FOR RESPONSE SELECTION IN COMPATIBILITY TASKS: REFERENTIAL CODING CONTRASTED WITH BIOLOGICAL PROPERTIES OF THE HANDS

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ABSTRACT

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Several researchers have hypothesized that the hands have unique effects on visual attentional resources and performance in response-selection tasks. This *hand-specific processing* hypothesis – that biological properties of the hands/palms uniquely affect visual attention and response selection – can be compared to a *referential object coding* hypothesis – that objects are coded in relation to other salient objects – favored in explanations of many compatibility effects. To test implications of these accounts, and specific effects that the hands (or general referential objects) have on attentional prioritization, I had participants perform three compatibility tasks using the hands or wooden blocks as referential objects. These objects were placed on a display screen such that they meaningfully segmented the space appropriate to response selection or in a position below the screen where they did not segment the space. Participants responded with a left or right foot-press response in all tasks, so that position of the response effectors was not confounded with that of the hands.

The Simon task evaluated whether hands differently affected the processes of selecting the correct response when the task was stimulus-property dependent: That is

to say, the goal of a left/right response was determined by a mapping of color to response. In the Simon task, a purple or orange circle appeared in the left or right location of the screen, each color mapped to a left or right response. Hands were placed such that either the left or the right hand was positioned at the middle of the screen or at the bottom of the screen (in separate blocks). The Stimulus−Response Compatibility (SRC) task utilized the same methodology, but rather than mapping color to response, participants were instructed to respond in separate trial blocks with the response at the same or opposite side as the stimulus. The SRC task evaluated specifically the effect of task instructions on the response selection and attentional processes. Thus, the Simon and SRC tasks together determined the effects of referential objects on attending to relevant features of the stimulus and improving performance when instructions, themselves, need to be attended.

Finally, the Stroop task tested one's ability to attend to the appropriate stimulus in an array of salient distractors. In the Stroop task, participants responded to the color of a bar presented on the screen along with congruent or incongruent color words. The bar could occur at the peripheral locations or centrally. Hands were positioned such that they either segmented the display, separating the targets from the distractors, or did not do soe (being placed below the screen). The Stroop task evaluated the impact on attention from distractors located in the visual array.

Across tasks, there was a reduction in the interference from incompatible/incongruent information when the hands and wooden blocks meaningfully segmented the display versus when they were located below it. This suggests a benefit of attentional focusing that occurs in the presence of meaningful referential objects which are positioned in such a way that response selection can occur in relation to them. That the hands and wooden blocks demonstrated similar effects suggests this referential coding is a more general effect and not specific to the hands. Finally, there were no differences when evaluating stimuli near the palm versus the back of the hands, which suggests the biological properties of the palms are not unique in attentional processes during response selection across compatibility tasks.

The experiments demonstrate two unique findings: 1) Hands and other referential objects effectively improve response-selection performance across a variety of compatibility tasks by reducing the impact of distracting information; 2) contrary to hypotheses regarding biological properties of the palms of the hands, responding to stimuli near the palms is not unique when a referential object meaningfully segments the display. Thus, referential objects seem to improve performance when their position segments the display to match the responses being selected.

INTRODUCTION

In the last decade, a divide has formed regarding response-selection mechanisms. From one viewpoint, embodied cognition proponents propose that the body is critical in selecting responses as it relates to the stimuli in some way (Anderson, 2003; Wilson, 2002). From another, though not completely unrelated viewpoint, information-processing advocates posit that people process, or code, stimulus information and select spatial response codes, rather than just make a response to a stimulus (e.g., Hoffman & Deffenbacher, 1992).

According to Clark (1998), "Biological brains are first and foremost the control systems for biological bodies. Biological bodies move and act in rich real-world surroundings" (p. 506). One specific theory has been cited that suggests the biological properties of the hands critically affect response selection in a variety of tasks (e.g., Davoli & Brockmole, 2012). This theory fits with the more encompassing scheme of embodied cognition because of the greater density of bimodal neurons that are present for the palm side of the hands (e.g., Brown, Morrissey, & Goodale, 2009; Davoli & Brockmole, 2012; Kao & Goodale, 2009).

Information-processing theory requires attentional mechanisms to acquire information into working memory, where it is actively manipulated, and long-term memory, where relevant information can be used in the future. In the information-processing approach, the human can be considered him/herself to be a complex system that works with and is related to other subsystems (see Broadbent, 1958; Fitts, 1951). Information processing occurs in stages: perceptual encoding, information translation, and response selection and execution (Rabbitt, 1979; see Figure 1).

The information-processing approach has been successfully used to explain many phenomena in basic and applied research relating to human cognition. Information processing is not an entirely disparate explanation from embodied cognition, which at its core is an information-processing approach. However, strict proponents of embodied cognition disagree with “disembodied”, information-processing theorists in the characterization of psychological phenomena (e.g., Mahon & Caramazza, 2008).

Embodied cognition advocates often cite James J. Gibson and his ecological psychology approach as the antecedent to the theory (e.g., Caligiore, Borghi, Parisi, & Baldassarre, 2010; Garbarini & Adenzato, 2004). Gibson's (1979) ecological psychology suggests that stimuli within the environment are directly perceived, thus requiring no additional cognitive processing (see Figure 2). Gibson thus considered the environment as the most important factor, suggesting that the direct perception of such affords specific actions for the organism. Additionally, Gibson was opposed to laboratory research in reduced laboratory environments, asserting that phenomena should be explored in real-world contexts.

Information processing can be used in applied experimental settings when the cognitive processing of an individual is considered as part of a system and is paramount in determining response selection, thus requiring further cognitive translation. This fundamental difference has led to much debate in cognitive psychology research and therefore deserves due diligence to determine what is occurring.

Information-processing theory uses an analogy in which a human mind is like a computer (McLeod, 2008; Sternberg & Sternberg, 2012). This theory suggests that the human is a component of a system and interacts with other components. Also, the human component passes through predictable steps of registering the information, translating it, acting upon it, and storing the information into memory for later use. The human 1) perceives information, 2) possesses set rules and strategies adopted through learning over time to transform the information, and 3) has a memory system to store information as well as the learned consequences of performed actions (see Figure 3). Critically, feedback from the environment is included in these stages that is necessary for a human as an information processor to create and maintain memory of consequences in certain situations (hence the elaborated Figure 3). These consequences can be ascertained because the human is an active component interacting with other components of the same system. Thus, the other system components and their reactions can be analyzed, understood, and learned by the human. Additionally, with increased time, rules can be altered and perceptions can be enhanced in order to more effectively select and execute responses.

In many of the previous studies that considered the biological properties of the hands as critical, spatial coding was confounded with the variables of interest. This was noted by Weidler and Abrams (2013), who cited many researchers who have reported changes in attention due to hand proximity (e.g., Abrams et al., 2008; Cosman & Vecera, 2010; Davoli, Brockmole, Du, & Abrams, 2012a; Reed, Grubb, & Steele, 2006; Reed, Betz, Garza, & Roberts, 2010; Tseng, & Bridgeman, 2011; Tseng, Bridgeman, & Juan, 2012).

Critically, Weidler and Abrams (2013) noted, "In each of these cases, the changes caused by hand proximity could all be explained by changes in the spatial allocation of attention" (p. 465). Also of importance in their study was the concluding remarks that the "results suggest that hand proximity affects the activation of the correct S-R translation rule" (p. 467). This is of utmost importance because the translation step between stimulus and response is an information processing account. The aforementioned studies all consider different tasks when researching the effects of the hands on attention or responding. Thus, to rectify the differences between the accounts and to take into consideration more recent findings of translation processes being affected by the hands, many different tasks must be evaluated to determine the underlying component that is leading to hand effects. Such evaluations will allow one to propose a mechanism that best fits the results. Finally, there is reason to consider the full gamut of compatibility effects in order to determine under which conditions and stimulus types that the effect will appear or not appear in order to have greatest understanding of the effects.

To accomplish this, I selected compatibility tasks, for which there are many variant paradigms (see Proctor & Vu, 2006, for a review), to undergo strategic and rigorous evaluation applied to many different experimental contexts in order to ascertain the most viable and parsimonious description of the mechanism involved.

There are numerous tasks that can be used in compatibility research, and each offers valuable information regarding an individual's perception, processing, and selection of responses. The motivation for selecting this methodology and examining several different compatibility paradigms for any underlying improvement on selection is: Each task relies on different sources of cognitive conflict; "For instance, mechanisms that filter out distracting visual information may be useful in the Flanker, Stroop, and Simon tasks, in which conflict is produced by competing irrelevant stimuli" (Nee, Wager, & Jonides, 2007, p. 6). However, the SRC task does not include visual distractors and thus does not suffer from the same source of competition of responses. Because the SRC task has been shown to share underlying neural correlates to resolve response-selection competition with flanker, Stroop, and Simon tasks (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Liu, Banich, Jacobson, & Tanabe, 2004; Nee et al., 2007; Peterson et al., 2002; Wager et al., 2005), it is necessary to determine if similar actions are able to be taken to reduce it across all tasks. As a result, there will be an understanding of how conflicting information is able to be ignored, suppressed, or resolved.

Thus, this dissertation takes knowledge from the four distinct compatibility tasks (the flanker task is identified in the background literature and past experiments I conducted; it is not directly tested in this dissertation, but its implications are discussed along with the other tasks) and uses a methodology that has been proposed to offer evidence consistent with an embodied cognition explanation by awarding the biological properties as the foundation for speeded reaction to visual stimuli. The ultimate goal is to determine why responses to specific target stimuli are speeded by the presence of the hand or other object in some conditions but not others.

Past Literature on Biological Properties of the Hands: Flanker Task

The following experiments all employed a modified version of an Eriksen flanker task. In the typical task (Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979), subjects are shown a string of letters and instructed to respond only to the centrally located letter. The other letters located to each side of the target, known as flankers, can either have the same (compatible) or opposite (incompatible) identity as that of the target stimulus. Stimulus identities are assigned a response at the beginning of the task for which the participant is instructed to respond. Thus, the flankers are known as distracting stimulus objects because they can lead to a deficit in choice reaction time (RT) and accuracy when the identities do not match. In such a task, when one separates the flanker-space from the target space using reference objects, there is a reduction in the interference. Prioritization of the space where the target is located suggests that referential objects can direct attentional resources appropriately in order to benefit response selection.

Davoli and Brockmole (2012)

Davoli and Brockmole (2012) were the first to demonstrate that a specific space within a visual scene is able to have enhanced attention compared to separate regions within the same visual space in a flanker task. In their study, they demonstrated that visual space located between the hands was enhanced compared to the region of space that occurred outside of the hand space. Thus, they concluded that the processing of the information outside of hand space was diminished due to the effect of blocking the processing of those stimulus objects. They suggested this blocking was a "physical manifestation of the attentional window" (p. 1386). The participants in Davoli and Brockmole's study performed a modified version of a flanker task. They were instructed to respond to a target letter that was located at a centrally located position on the computer screen. In each trial, the target letter was accompanied by two instances of an identical flanker letter that was either compatible (indicated the same response) incompatible (indicated the opposite response) or neutral (indicated no response) with the identity of the target letter.

In Experiment 1, participants were instructed to place their hands either around the letters or away from the letters off to the side of the screen. In Experiment 2, the away condition was modified such that the participant now held their hands directly in front of them but below the letters. Across both experiments, there was a reduction in flanker interference (incompatible − neutral trials) in the hands-between condition when compared to the hands-below condition. Davoli and Brockmole (2012) suggested that this result indicates that the hands shield attention from the interfering letters.

Murchison and Proctor (2015a)

Using the same methodology as the previous experiment, an alternative hypothesis was explored. Instead of attributing the reduction in flanker interference to an attentional window specific to the space between the hands, a referential coding account was presented. In this alternative hypothesis, the hands provide a frame of reference for which participants are able to direct attention appropriately based on instructions provided.

Importantly, to directly examine the benefit of the palms of the hands, separate conditions were tested in which the outside letters were identified as the target letters, making the centrally-located letter the distracter. Results demonstrated a comparable reduction in flanker interference between conditions in which the outside letters were the targets as when the inside letter was the target. This result is contrary to the suggestion that the palms of the hands are special in their ability to direct attention. In a separate experiment, wooden blocks were used in place of the hands to test whether the hands were necessary to receive such a benefit. In this case, there was a reduction in flanker interference for the target-inside condition, as in the previous experiments. Thus, there was support that the reduction in flanker interference was due to referential coding and the benefit came about by more efficiently directing attentional resources to appropriate location relative to a reference object.

Murchison and Proctor (2015b)

In another set of experiments, hands were crossed so that the palms now faced the outer letters with the back of the hands facing inward in order to further test the explanation that the palms of the hands are unique in their ability to speed responses in an Eriksen flanker task compared to other body parts or other objects. As in Murchison and Proctor (2015a), there were separate conditions in which the centrally located letter and the outer letters were designated as the target to which a participant is to respond to the identity of the letter. Across conditions results revealed the same reduction in flanker interference for both inside-target and outside-target conditions. This finding provides confirmatory evidence that the back of the hands can receive the same benefit as the palms of the hands when participants are instructed that the area is that where they must focus in order to effectively respond. Thus, a referential coding account is most parsimonious to explain these results.

Compatibility Tasks

In order to realize how one is able to prioritize space for better responding, a variety of tasks can be performed that yield compatibility effects of one type or another, for which there are certain conditions in which responding is faster and more accurate than others. There are four distinct tasks that are discussed in this dissertation, three of which underwent experimental manipulation to determine under what conditions and for which stimuli a referential object in the form of the hand can be utilized to improve response selection and execution. The experiments on the fourth task, that of flanker compatibility, were conducted previously and were discussed in the previous section.

In the Stroop color-identification task (Stroop, 1935; reprinted Stroop, 1992), participants are shown color words that can be presented in the same (compatible) or a different (incompatible) color from the meaning of the color word. They are instructed to ignore the text and respond to the color of the word. In a modified methodology, Kim, Cho, Yamaguchi, and Proctor (2008) tested whether the Stroop effect is a consequence of reading being automatic or words capturing attention by having participants respond to color bars with color words presented at simultaneously. In such arrangements, choice RT is faster for compatible trials when compared to incompatible counterparts (Glaser & Glaser, 1982; MacLeod, 1991). This finding is important for determining the conditions under which one can prioritize specific properties of a stimulus. In the Stroop task, the very first recognizable quality of the stimulus − its physical appearance − is not what a participant uses automatically for responding. For incongruent trials, when the color word is different from the response that is to be given as dictated by the physical appearance, there is a deficit in responding.

From the Stroop task, it is known that the word definitions impact response selection, and are automatically prioritized over physical properties. It has also been shown in Experiment 1 that in the Simon task, a referential object in the form of the hand, was able to aid in response selection when the physical properties of the stimulus were paramount for selecting the correct response. Thus, if this is able to be shown for the Stroop task in a modified version of the task, this would suggest that a referential object is able to overcome instinctual responding when instructed to do otherwise.

In SRC tasks (Fitts & Deininger, 1954; Fitts & Seeger, 1953), stimuli that differ in spatial location are shown to participants, and they are to make spatial responses. In this set-up, RT is faster and accuracy better when the stimulus location and response to be given agree in spatial location (congruent) than when they disagree (incongruent; Duncan, 1977; Hommel & Prinz, 1997; Reeve & Proctor, 1990). This can be completed by instructing participants to respond in the same or opposite direction as the stimulus that is presented. Thus, the instruction the participant is given is the critical factor for determine the response that is to be made. From Murchison and Proctor (2015a), it was established that one could prioritize space relative to a referential object given the instruction that was provided to the participant at the beginning of the task. Thus, by manipulating referential objects within such a task in which a participant is instructed to respond at the same or opposite stimulus location, it can be determined if the rule used to select responses is able to be prioritized above the automatically processed physical location of the stimulus that would lead to compatibility effect differences between conditions.

In Simon tasks (Simon, 1969, 1990), participants are instructed to respond to a physical property of a stimulus, such as stimulus color. In the two-choice task, there are two separate colors in which a stimulus can appear, and they are assigned to left/right responses. Additionally, the stimulus can be presented to the left or to the right side of the display area. Thus, a stimulus can be corresponding, in which the location and the assigned color indicate the same response, or noncorresponding, in which location of the stimulus and the assigned color response are different. In such a task, one is able to determine how physical properties of a stimulus are able to be prioritized and responding made more efficient by the presence of a referential object. Should this prioritization occur, it would suggest that the referential object is specific to the assignment of the instructed properties one is to use when making responses.

It has been demonstrated that there are many different compatibility effects, and for each we are able to develop more knowledge about response-selection processes in many types of situations. According to Zhang, Zhang, and Kornblum (1999), while these tasks are generally studied in isolation, there have been attempts to determine underlying relationships between them (e.g., Cohen et al., 1992; Kornblum et al., 1990; Lu & Proctor, 1995). One well-known model that has been proposed to integrate these compatibility effects is the dimensional-overlap model (Kornblum, 1992, 1994; Kornblum et al., 1990; Kornblum & Lee, 1995), for which similarities in dimensions between stimuli and responses are used to make ordinal predictions about response execution. With successful attempts of unifying various compatibility tasks having been established, it stands to reason that there may be some means of improving performance systematically across deficit conditions.

A reduction in interference has been demonstrated in flanker studies with wooden blocks and hands as referential objects; it is worthwhile to explore possibilities that this transcends compatibility phenomena and can be applied to real-world situations. This possibility has value both in basic and applied experimentation because a deeper understanding of the mechanism for response selection as well as response execution being efficient (maximally fast and accurate) is of utmost importance. According to Zhang et al. (1999), there are likely similar mechanisms at play for response-selection stages across Stroop, SRC, Simon, and flanker tasks. Thus, if a referential object is affecting response selection by directing attention to the location or physical identity of target stimuli in one task, it should occur analogously across tasks that share a mechanism. This is possible because the effects work under a similar mechanism and is important because responding may be improved under certain task conditions.

Sequential Effects

Sequential effects in the compatibility literature offer insights into the impact of a previous trial on the response selection for the current trial (Kirby, 1980). Congruency sequence effects (CSE) are characterized by a larger congruency effect following a congruent trial than following an incongruent trial, in flanker (Nieuwenhuis et al., 2006), Simon (Chen & Melara, 2009), and Stroop (Notebaert, Gevers, Verbruggen, & Liefooghe, 2006) tasks (i.e., all tasks in which there is an irrelevant dimension). One account of this sequential effect pattern is modulation of a direct or automatic response-selection route as a function of whether the prior trial was congruent or incongruent. For example, Kunde (2003), states, "More importantly, however, this sequential modulation was present only when the source of response conflict (the prime) was clearly perceptible, which suggests that conscious experience of a preceding response conflict is a necessary precondition for these sequential modulations to occur" (p. 201).

Sequential effects have been found to be affected by nearby hands in a modified flanker experiment. Englert and Wentura (2016) had participants respond to the centrally presented letter in an array of five congruent or incongruent letters. The letter's identity was mapped to a left or right response that was administered using a mouse-press in two different hand postures. The first posture was near the display, in which the hands were located to either side of the computer monitor. The far posture had the participants' hands' horizontal separation at the same distance, but at a location below the screen, away from the display. The authors reported a reduction in the sequential effects for nearby hands, when the hands were placed near the display. The authors suggest that they "found no support for a modulation of the Eriksen flanker effect corresponding to the interaction found by Weidler and Abrams (2014, Exp. 1). On the other hand, we found evidence of CSE modulation that is compatible with Weidler and Abrams' general notion" (p. 7). More generally, this modulation of the CSE was interpreted as enhanced cognitive control near the hands.

The CSE is critical for the current discussion, as the hands may impact attention by providing an object by which participants can define the visual space, thus allowing participants to ignore the irrelevant information on incongruent trials. If sequential effects are reduced similarly for hands and artificial barriers in the between posture versus the below posture, this outcome would suggest that attention is not oriented to the incongruent information, but this effect is not limited to the hands. Analyses of CSE will be included for the experiments that involve irrelevant stimulus information, Experiments 1 and 2 on the Simon task and Experiments 5 and 6 on the Stroop task.

Referential Coding in the Simon and SRC Tasks

There is a long history of explaining compatibility tasks in terms of referential coding, and the Simon task is no exception. In describing the frames of reference with regard to the Simon task, it is argued that the coding of stimulus is dependent upon the availability of a referential object from which to define the responses (Hommel, 1993).

Additionally, this effect has been demonstrated to be "functionally related to the position of the focus of attention" (Stoffer & Yakin, 1994, p. 151). This finding is critical for the set of Experiments to be completed below because, consistently across manipulations, the referential object can be utilized by participants in order to determine the focusing of attentional resources. Thus, the reduction that was demonstrated in that study, if replicated in this study as an effect of the referential objects available, would suggest that the referential object is serving as a starting position for attentional resources. This set of experiments adds to this set of findings by including the extent to which a goal is also implicated in the referential coding account.

According to Stoffer (1991, p. 127), there will be a deficit in responding for incompatible trials

> … if the side of the response does not correspond to the side of the stimulus in relation to a neutral position that may not be the body midline, but can be an external reference point (e.g., Nicoletti, Anzola, Lupino, Rizzolatti, & Umiltá, 1982; Nicoletti, Umiltá, & Ladavas, 1984…). This is true not only for the spatial compatibility effect proper, but also for the Simon effect (Simon, 1968, 1969; Umiltá & Liotti, 1987; Wallace, 1971).

As with the Simon task, frames of reference have been implicated as impacting the patterns of results in the SRC task. As mentioned above, this reference frame need not be the midline of the body, but can be external factors of a wide variety (Hommel, 2011; Hommel & Lippa, 1995). These frames of reference include hemispace, hemifield, and critically, the relative position (Lamberts, Tavernier, & d'Ydewalle, 1992). All three of these have been demonstrated to impact SRC proper. This suggests that codes utilized by the cognitive system interact with the representations of response in terms of the relative spatial locations. As with the Simon task literature, the present experiments will make a significant contribution to understanding the implications of referential coding in the SRC task by determining the specific differences between hands versus other barriers. Additionally, by comparing the two tasks, the experiments will provide a clearer understanding of how physical versus goal-related properties relate.

Role of Attention in the Stroop Effect

A phenomenon known as the Stroop dilution effect implies a role for attention in the Stroop congruency effect. The critical experiments that relate to this current work were completed by Kahneman and Chajczyk (1983), who used the same modified Stroop task as in Experiments 5 and 6 of the present study. The task requires participants to respond to the color of a bar, with conflicting or non-conflicting distractors in the form of color words presented. Kahneman and Chajczyk's findings demonstrate a reduction in the Stroop interference effect due to the presence of a neutral word presented along with a distractor and with a row of neutral X's. Thus, the "dilution effects represent attentional interference rather than sensory interaction or response conflict" (p. 497). The current set of studies is impactful, because if a similar reduction is found in Experiments 5 and 6, that result will suggest that the reduction in interference is due to the attentional demands not being diminished by the involuntary processing of the color word. Additionally, it will provide evidence of the role of attention in the Stroop task through an effect of a referential object rather than neutral words.

According to Brown, Roos-Gilbert, and Carr (1995), the features of the dilutor are critical by degrading the processing of the words, which is "outside of the word recognition per se" (Brown, Gore, & Carr, 2002, p. 229). That is to say, this would occur in early, thus the color words would not be attended to or processed, which leads to the reduction in the Stroop interference effect. Brown et al. (1995) used a series of string of dilutors including equal signs, brackets, dashes, etc., and in two experiments demonstrated the dilution of the Stroop effect was of a similar magnitude to that of the dilution due to neutral words.

Kim et al. (2008) suggested,

> The lexical status of dilutors is not important in determining the magnitude of the Stroop dilution effect… When a dilutor is presented simultaneously with a color word, feature processing of the color word is degraded, resulting in the reduced efficiency of lexical encoding operations, which provide the basis for word recognition processing. (p. 1541)

To the extent that the hands and artificial blocks decrease the magnitude of the Stroop effect, this provides confirming evidence that attentional resources may be more appropriately focused to the exclusion of the distracting words. Additionally, the extent to which findings from the hands and wooden blocks are in agreement would demonstrate a general implication of the attentional focusing based on these results. This area of research provides further rationale for including the modified Stroop task in this set of experiments because it demonstrates an overall impact of attention that may be cohesive across tasks if referential objects are behaving in a similar way across compatibility tasks.

Endogenous vs. Exogenous Control of Attention

That there may be a shared mechanism between the various compatibility paradigms studied in this group of experiments would suggest an overall attentional mechanism that is benefited by the referential objects (be it hands or artificial blocks).

Visual attentional resources may be driven by either exogenous or endogenous systems of control. Exogenous control is stimulus-attribute driven, whereas endogenous control depends on the goals of the task (which can be the instructions given at experiment onset, as was demonstrated in Murchison and Proctor (2015a). According to Theeuwes (1994, p. 429),

> When an observer intentionally selects from the visual field only those objects which are required to perform the task at hand, selection is thought to occur in a goal-directed, voluntary manner. When specific properties present in the visual field capture attention independently of the observer's goals and beliefs, selection is thought to occur in a stimulus-driven, involuntary manner. These two mechanisms of selection have been referred to as endogenous and exogenous control, respectively.

Thus, for situations in which the compatibility effect arises as a consequence of the instruction, such as SRC, the studies below will determine if there is likely endogenous control of attentional resources that is intentionally driven by the participants. In addition, the Simon and Stroop tasks will further determine the extent to which exogenous control, from stimulus properties, is also at play.

Study Implications

The critical question is the extent to which referential objects have similar or different overall effects on modulating compatibility effects as a function of the task demands that characterize the different compatibility effects and the means by which the critical relationships are established. If the effects interact, there is evidence for a shared mechanism across the tasks, which is likely spatially driven and arises from the meaningful segmentation from a referential object, as has been suggested by Murchison and Proctor (2015 a, b). For each of the compatibility tasks being studied, the effects arise by some relationship between stimulus and response matches or mismatches interacting to affect both speed and accuracy.

The extent to which there is some meaningful overlap between the stimulus and the response codes, the better the performance will be for both performance measures. Critically, when there is an addition of a referential object that spatially segments the space into hemifields, this frame of reference is applicable to both the stimulus and the responses in terms of the spatial relationship they each share. Thus, there is cause to think that the referential object will benefit responding in multiple compatibility tasks by virtue of introducing a referential code that is the basis for dimensional overlap between the stimuli and responses (for more on the dimensional overlap model, see Kornblum et al., 1990).

The research has implications for both the response-selection mechanism in general and the hypothesis that knowledge about the biological properties of the hands specifically is critical, as suggested by the embodied cognition approach. First, it offers insight into the process of response selection, assuming an information-processing approach, by indicating under what conditions and specific types of stimuli a reduction in interference between competing responses can be realized.

Second, it provides insights regarding embodied cognition for arguments that assume uniqueness for the palms of the hands. Because this research directly compared the backs from the palms of the hands across paradigms, evidence for how the hands serve a benefit emerged. Because it was revealed that the backs of the hands received a benefit to the same extent as the palms, the results provide evidence against embodied cognition specific to the bimodal neuron explanation for palm-specific benefits.

This study was conducted with a similar methodology to that of Murchison and Proctor (2015a), with amendments made when necessary. Critically, this methodology used foot-press responses to dissociate hand placement from how responses are being made, which allowed a cleaner assessment of hand effects. In Experiments 1, 2, and 4, separate conditions of left and right hand in between and below space were evaluated for both the effects hands in general have on attentional resources as well as differential effects of each of the hands. A lack of effect of the specific hand used would provide evidence counter to the biological properties of the hands being important, for which the theory predicts differences between the two hands (e.g., Tseng, Yu, Tzeng, Hung, & Juan, 2014); rather, such a result would imply that the hands are serving as a frame of reference. Experiment 3 replicated the methodology exactly from Murchison and Proctor (2015a) but with a modified Stroop task rather than a flanker task to determine whether a reference frame allows better selection of the target when the distractor has a conflicting word meaning.

The experiments provide evidence regarding the following about response selection, the effect the hands have on it, and the likely mechanism for the effects:

1) The stimulus conditions under which the hands have an effect: A) when physical stimulus properties dictate responding as in the Simon task; B) when directions provide a rule for responding, as in Murchison and Proctor's (2015b) study of the flanker effect, confirmed in the present research by the SRC task; C) when physical separation between targets and flankers exists, as in Murchison and Proctor (2015a), confirmed in this study by the modified Stroop task.
2) Whether the hands be used to suppress the interference from automatically processed stimulus dimensions of A) the location as in the Simon and SRC tasks and B) text definition as in the Stroop task.

Thus, the Simon task in Experiments 1 and 2 provides evidence relevant to whether physical properties of a stimulus are prioritized such that response-selection processes are benefited in the presence of a referential object. Referential coding has been successful in accounting for results in Simon tasks, as discussed above, which leads to the expectation that coding with reference to a hand or wooden block should reduce the Simon effect, extending results to the type of object utilized. Furthermore, hand location and stimulus location will be dissociated to determine if the most likely explanation for the effects are due to the biological properties of the hands with a palm-specific benefit or referential coding.

In Experiments 3 and 4, the ability of attentional resources to be directed differentially due to hand locations and artificial barrier locations was evaluated in terms of instructions given in an SRC task. It was hypothesized there would be no differences due to target location, as it had been demonstrated that resources can be directed inside or outside depending on instructions given to participants (Murchison & Proctor, 2015a, b). In this case, rather than indicating the location of the target, the instructions provided the rule by which the participants decided responses. Instead of determining whether the hands are able to prioritize a visual space, this experiment evaluated whether the hands are able to affect response-selection processes specifically. In this case, compatibility is determined by stimulus dimensions. Rather, in SRC, compatibility requires translation of the stimulus to a response that is entirely goal-driven. By providing an object by which the goal can be more effectively strategized, there should be faster responding overall. Thus, the same reduction of the incompatible trials should be discovered which will be driven by a referential object with which to organize the space and their responses according to one central location. I also was able to dissociate the palm from the back of the hand to decide the appropriate mechanism. This experiment provides evidence as to whether unknown stimulus locations are able to benefit from a referential object in the form of the hands.

In Experiments 5 and 6, a Stroop task was used to determine the extent to which the hands and artificial blocks are able to overcome automatically processed stimulus properties – in this case, definition of the stimulus words. This employed the same methodology as that in the prior flanker experiments (Davoli & Brockmole, 2013; Murchison & Proctor, 2015a). Results from previous studies are thus extended here because in the flanker task, the basis for the effect is through a task-specific association (assignment) of letter-stimuli that are both physically similar and categorically similar to responses. In the Stroop task the color word has only a categorical, or conceptual, relation to the target. Hence, these experiments provide evidence as to the categorical overlap between stimulus and response, specifically.

I hypothesized that if there is a difference between previous results obtained with the flanker task compared to the current experiments, then the hands are affecting processing differently from artificial barriers when evaluating categorical relationships. To evaluate this, I dissociated stimulus location from the palms of the hands by having targets inside and outside as well as crossed and uncrossed hand positions. This methodology is constructed to determine the likely mechanism – biological properties or referential coding. If there is an interaction between the compatibility effects, the hand position, and the relationship between the stimulus and the hands, then this would indicate something specific to the biological properties of the hands with regard to processing stimuli falling near them. It is hypothesized that this three-way interaction will be non-significant, which will provide evidence for the referential coding account.

EXPERIMENTS 1 AND 2: THE SIMON TASK

The Simon task is one in which the appropriate left or right response is dictated by some physical property of the stimulus other than its location, which varies between left and right randomly from trial to trial. Even though stimulus location is task-irrelevant and should be ignored, a congruency effect occurs for which responses are faster when stimulus location is congruents with response location than when it is not. Thus, this set of experiments using the Simon task examined the extent to which a goal that is tied to a physical component of the stimulus itself, rather than location or instructions, is benefited by a referential object. This is an influential manipulation because the physical properties of a stimulus were pitted against the physical/biological properties of the hands when comparing Experiment 1, in which the hands were referential objects, and Experiment 2, in which artificial wooden blocks were the referential objects.

As mentioned, in Experiment 2 a wooden block, cut to mimic the size an adult hand, was used as the referent on the display screen. When comparing between Experiments 1 (hand) and 2 (wooden blocks), it is hypothesized that if there are divergent findings between them with regard to the reduced interference effect, then the manipulation suggests that there is something specific to the hands; conversely, if a similar pattern of results is found, then the more likely explanation is that the mechanism is one of attentional prioritization more generally, thus consistent with a referential coding account. Additionally, there is a direct test of the criticality of the palms of the hands in Experiment 1, which will look at the differences in the interference effect when the stimulus occurs at the palm rather than at the back of the hand.

Experiment 1: Simon Task with Hands as Barriers

Method

Participants. Participants were 64 undergraduate students (38 males; 59/64 = 94% right handed) who received credit toward a course requirement in their Introductory Psychology class. All had normal or corrected-to-normal vision. An a priori power analysis performed using G*Power (Buchner, Erdfelder, & Faul 1997) revealed that a power of 0.95 for the 0.05 criterion using the $\eta_p^2 = .092$ from Murchison and Proctor (2015a) for the barrier × congruency effect interaction of interest requires a minimum of 30 participants.

Apparatus, stimuli, and procedure. The experiment was conducted using a personal computer controlled by E-prime 2.0 software (Psychological Software Tools, Inc., Sharpsburg, PA). The stimuli were purple and orange circles that were 11-cm diameter (9.3° visual angle), shown on a white background on the monitor screen, at a left or right location that was 11.8 cm (10°) from the screen center to the circle center (see Figure 4). Participants input their responses to the color the target (purple or orange) using the two foot pedals, one positioned below each foot. Stimuli were displayed on a 19-inch monitor, laid down on the desk. Participants sat approximately 67 cm from the screen. Prior to beginning, the experimenter explained the general instructions and demonstrated the appropriate hand placements for each of the trial blocks in the experiment: left/right-hand between and left/right-hand below. Instructions, which indicated where the participant was to hold his/her hands and the mapping of the color to responses, were given on the computer screen before each block. Once this was completed, the experiment began.

The study used a mixed design. The within-subject manipulation was the four separate hand-placement conditions, conducted in four separate trial blocks (right-hand between, left-hand between, right-hand below, and left-hand below); the between-subjects manipulation was whether the hand was placed with the palm facing naturally, or turned to face outside. In the right-hand between condition, the right hand was placed in the center of the screen, directly between the two stimulus locations (7.7 cm or 15º) such that the palm faced the left side of the screen and the back of the hand was at the right side of the screen. In conditions for which the palm faced outward, the hand was switched such that the palm faced toward the right and the back of the hand to the left (see Figure 4). For the right-hand below condition, the right hand was placed over the "Dell" icon located at the bottom of the computer screen. Analogous hand placements were used for the left-hand between and below conditions. In all cases, participants were instructed to hold their hands straight (no curve of fingers of palms) in order to minimize any spatial effects between conditions as much as possible.

Stimulus colors were mapped to left and right responses, counterbalanced across participants. For half of the participants a purple circle would indicate a right response, and an orange circle would indicate a left response, whereas for the other half of participants the color-response mapping was opposite. If the location of the stimulus matched the assigned response of the color, then that was a congruent trial; whereas if the color and the location of the stimulus disagreed, this was an incongruent trial. Each block contained 72 trials (36 each of congruent and incongruent trials), for which order was randomized. In each hand-between (those situations in which the hands occur at the position between the two potential stimulus conditions) condition, participants were instructed to hold the respective hand 5.7 cm away from the target circle, at the center of the screen.

In both conditions, participants were told not to use their hands to physically block the peripheral stimuli. Prior to each block of experimental trials, 14 practice trials (7 each of congruent and incongruent) were given to make sure that the participant understood the instructions for that block. Also, the experimenter remained in the room for the duration of the experimental session, seated in a corner located behind the participant, to ensure that the participant's hand positions remained constant and that there were no problems or questions. Participants were instructed to respond as quickly and accurately as possible. Stimuli remained on the screen until a response was registered, and feedback was given afterward: for incorrect trials, "Incorrect!" appeared in the upper left hand corner of the screen in red ink for 300 ms; for correct trials, "Correct!" appeared in the same location in blue ink for 300 ms. After that, there was a 200-ms delay prior to the next trial. Before the experiment, participants were told which stimuli were assigned to the respective responses, and this assignment remained constant throughout the experiment.

Results

Outliers in the RT data were determined using the criterion applied by Davoli and Brockmole (2012): For each participant, the mean and standard deviation (*SD*) for each hand placement was calculated, and trials with RT greater than three *SD*s of the mean (approximately 1%) were excluded. Any participant making more than 20% incorrect responses was to be replaced, but no participants were excluded on that basis. Data were collapsed for left/right hand because there were no significant differences between them, $F(1, 63) = 0.55$, $p = .460$. A 2 (hand placement: hand-between or hand-below) × 2 (congruency: congruent or incongruent) × 2 (Stimulus-to-Hand Relation: palm or back of the hand) analysis of variance (ANOVA), was performed separately for RT and PE (see Table 1 and Figure 5; for complete results, see ANOVA table in Appendix A). For the latter factor, when responding with the right hand in a normal position, the left stimulus is coded as palm-side and the right stimulus as back-side, and vice versa for the left hand facing normally; when responding with the hands facing outward, these relationships are opposite.

Reaction time. The ANOVA revealed a significant main effect for the hand placement, $F(1, 63) = 5.06$, $p = .029$, $\eta_p^2 = .074$, with longer RT overall for the hand-below condition ($M = 623$ ms) than for the hand-between condition ($M = 606$ ms). There was also a significant main effect of congruency, $F(1, 63) = 91.82$, $p < .001$, $\eta_p^2 = .593$, with responses slower overall on incongruent trials ($M = 634$ ms) than on congruent trials ($M = 595.5$ ms). Finally, the interaction between hand placement and congruency, $F(1, 63) = 21.18$, $p < .001$, $\eta_p^2 = .252$, revealed a reduction in interference for the hand-between placement compared to the hand-below placement, as indicated by a smaller Simon effect for the former (15 ms) than for the latter (62 ms). This difference was due to the incongruent trials showing a larger reduction in RT in trials when a hand was located between the two possible stimulus locations.

Importantly, there was no difference between the location to the palm-side (Compatibility Effect, CE = 25 ms) and back-side of the hand (CE = 24 ms). The stimulus-to-hand relation (palm vs. back of the hand) was not significant, $F(1, 63) = 0.07$, $p = .796$. This is a critical finding for this experiment. It replicates the findings from Murchison and Proctor (2015a, b) as well as provides evidence that the palms of the hands are not unique in their ability to direct attention to the appropriate attention above and beyond other parts of the hands.

Percent error. The ANOVA revealed a significant main effect of congruency, $F(1, 63) = 19.42$, $p < .001$, $\eta_p^2 = .236$, with congruent trials ($M = 1.8\%$) responded to more accurately than incongruent trials ($M = 3.0\%$). The interaction between the stimulus-to-hand relationship and hand-placement condition was significant, $F(1, 63) = 6.12$, $p = .014$, $\eta_p^2 = .092$, which is due to a greater overall difference between the palm- and hand-sides in the below condition, which was exacerbated in the instances for the outward facing palms, likely due to the awkward positioning. Note, though, that this difference does not involve congruency.

Experiment 2: Simon Task With Wooden Blocks as Barriers

Method

Participants. Participants were 32 new undergraduate students from the same participant pool as in Experiment 1. All had normal or corrected-to-normal vision.

Apparatus, stimuli, and procedure. No changes were made in the methodology in Experiment 1 except that a wooden block replaced the hand in the positions on the display screen. The block was 4-in long × 1-in wide (see Figure 4), and participants kept both hands in their laps for the duration of the experimental trials. The block that was utilized in this study was designed to approximate the physical size of an adult-male hand.

Results

Reaction time. The ANOVA revealed a significant main effect for block placement, $F(1, 31) = 6.61$, $p = .015$, $\eta_p^2 = .176$, with longer RT for the block-below condition (M = 615 ms) than for the block-between condition (M = 596.5 ms). There was also a main effect of congruency, $F(1, 31) = 126.53$, $p < .001$, $\eta_p^2 = .803$, with incongruent trials (M = 610 ms) being responded to slower overall than congruent trials (M = 601.5 ms). Finally, the interaction between block placement and congruency, $F(1, 31) = 25.04$, $p < .001$, $\eta_p^2 = .447$, indicated a smaller congruency effect for the block-between placement (CE = 5 ms) than for the block-below placement (CE = 12 ms). No other effects reached significance, $Fs < 1$.

Percent error. The ANOVA revealed no significant effects, $Fs < 1$.

Between-experiment comparison. An additional 2 (Barrier) × 2 (Congruency) × 2 (Experiment) ANOVA was conducted to compare the analogous effects between Experiments 1 and 2. The overall congruency effect was significant, $F(1, 93) = 40.93$, $p < .001$, $\eta_p^2 = .406$. Notably, the congruency × barrier interaction was also significant, $F(1, 93) = 21.45$, $p < .001$, $\eta_p^2 = .263$, showing that the interference effect was modulated by presence of a referential object, be it a hand or wooden block. There was a significant interaction between experiment and congruency, $F(1, 93) = 8.77$, $p = .004$, $\eta_p^2 = .126$, which reflects a larger overall Simon effect in the hand experiment compared to the block experiment. The experiment × barrier × congruency interaction, $F(1, 93) = 4.73$, $p = .034$, $\eta_p^2 = .073$, was also significant: The reduction in interference was larger, but in the same direction, when the hands were used as barriers compared to the wooden blocks. Both of the interactions involving experiment are likely due to the larger base Simon effect for the "below" barrier placement in Experiment 1 than in Experiment 2. Thus, the results indicate that the reduction in interference across Experiments 1 and 2 is qualitatively similar, although somewhat different in magnitude. Finally, no other effects reached significance, $Fs(1, 93) < 1.93$, $ps > .170$. Finally, the lack of critical differences between Experiments 1 and 2 suggests that not only do the palms not uniquely affect attention compared to the palms, but there is also not evidence that the palms uniquely impact performance compared to other referential objects.

With regard to accuracy, the only significant interaction in terms of experiment was that between barrier and experiment, $F(1, 93) = 5.28$, $p = .024$, $\eta_p^2 = .053$, for which there was a greater effect of the hands in Experiment 1 than of the blocks in Experiment 2. Since there was no impact on the congruency effect, the posture does not impact the critical finding of reduced interference due to the position of the hands.

Sequential effect analysis. As noted, Englert and Wentura (2016) found that the congruency sequence effect (CSE) – a larger congruency effect following a congruent trial than following an incongruent trial – in a flanker paradigm was eliminated when the hands were located near the display compared to when they were located far from it. They interpreted this result as enhanced cognitive control when the hands are located near the display. To test the impact that referential objects have on the CSE, a similar analysis was done in a repeated-measures ANOVA, with factors of barrier type (hand versus wooden block), barrier location (between versus below), current trial congruency (congruent or incongruent) and previous trial congruency (congruent or incongruent). Results indicated a significant CSE, $F(1, 93) = 77.40$, $p < .001$, $\eta_p^2 = .572$: When the previous trial was congruent, there was a large congruency effect (CE = 52 ms), however, when the previous trial was incongruent, the congruency effect was absent (CE = −1 ms; see Figure 6). The interaction between CSE and barrier location was significant, $F(1, 93) = 4.20$, $p = .045$, $\eta_p^2 = .068$: The CSE was larger when the barriers were located below the stimuli (CSE = 27 ms) rather than between them (CSE = 12 ms). However, the CSE did not interact with barrier type, $F(1, 93) = 2.28$, $p = .136$, nor was there a four-way interaction between barrier type, barrier location, current trial congruency, and previous trial congruency, $F(1, 93) = 0.20$, $p = .656$.

Discussion

The results from Experiment 1 demonstrate a similar pattern as those in the previously discussed studies that used a comparable methodology (e.g., Murchison & Proctor, 2015 a, b). That is, there was a reduction in the congruency effect in the hand-between condition compared to the hand-below condition. This reduction was due to faster responding in the incongruent trials when the hands were located between the stimuli compared to when the hands were located below the stimuli.

This pattern indicates that participants were able to prioritize not specifically space relative to a reference object, but the relevant physical properties of those objects within that space when that physical dimension has been indicated to be necessary for responding correctly. This result suggests that the hands are not blocking out irrelevant information from a different area within the visual space, but rather prioritizing the dimensions of stimuli to which one has to attend in order to respond appropriately. This ability led to faster responding, which suggests more efficient processing of stimuli within the space of directed attention.

This finding works against the hypothesis that the palms are unique in prioritizing space by blocking out other spaces (e.g., Davoli & Brockmole, 2012). First, the benefit was realized for both the palms and the back of the hands. Second, in a Simon task, the intruding information is contained within a single stimulus. The simplest explanation for receiving such a benefit as a result of the hands in the space is that the cognitive processing that occurs when one is translating the stimulus into correct response execution is benefited by a referential object being located between the object to prioritize relevant stimulus properties. The finding that incongruent trials were affected more by the hand placement than were the congruent trials in a situation in which stimulus dimensions are relevant for responding is consistent with previous studies evaluating referential coding.

The results from Experiment 1 showed a reduction in the congruency effect in the hand-between condition compared to the hand-below condition in Experiment 1. A qualitatively similar pattern was realized when artificial blocks were used in lieu of the hands in Experiment 2, suggesting the reduction is not a consequence of a specific biological property but of a general property of referential objects. However, that the quantitative difference in the pattern of results in Experiments 1 and 2 suggests that the similar patterns in Experiments 1 and 2 may not simply be an effect of relative spatial coding, but that the mechanism may be different when dealing with the hands rather than with artificial blocks.

The physical properties of the wooden blocks made them a less substantial barrier object than the hands (thinner in width than and not as long as an adult-male hand). This physical distinction is one difference between the tasks that may explain the slight differences that were observed between Experiments 1 and 2. This outcome suggests that the referential coding may not be a guaranteed effect if the referential object does not allow for a strong-enough starting off point for attentional resources. It may also mean that a 3-dimensional object is required if one quality of the referential object is that it be substantial.

Another possibility is that because the hands were located in a different place in Experiment 2 (both hands in the lap) compared to Experiment 1 (one hand at the bottom of the display screen or between the two stimulus locations), that the placement added to the effect. This difference is mainly in the below conditions. Such a result implies that either that the wooden block is a more effective barrier than the hand in the below condition or that having the hands in the lap reduces the Simon effect. It is doubtful, however, that this factor would be consequential because 1) the feet were making the responses rather than the hands, meaning that location is not confounded with responding, and 2) there was no difference in where the hands were placed in the below conditions for the hand and block barrier experiments in prior studies (e.g., Murchison & Proctor, 2015 a, b). Nevertheless, any difference between the two methods would need to be explored in order to determine the source of the discrepancy. Regardless, these hypotheses fall outside of the scope of this project, which is determining the processes of translation and response selection in compatibility tasks that are influenced by referential objects, and whether the biological properties are a necessity for a reference object to be effective, but pose an interesting research question for later work.

Although there were slight differences between the hands and wooden blocks as barriers, when considering the sequential effects, as in Englert and Wentura (2016), it appears that attention is positively impacted by any referential object because the lack of four-way interaction indicated that there was not a difference between the hands versus wooden barriers, this outcome suggests that spatial coding is impacted by a referential object. When evaluating the sequential effects, results demonstrated that just as the current incongruent trial did not have as much of an impact on responding (reduction in interference for barrier-between trials), the prior incongruent trial (trial *n*-1) also did not impact response selection, which accounts for the lower overall sequential effect. That is to say, the incongruent information is not paid attention to on the current trial, *n*, and analogously, does not impact trial *n*+1 (there is not a cost for an incongruent trial following a congruent one, nor a gain for two consecutive incongruent trials when referential objects segment visual space). Thus, by evaluating the sequential effects in this case, there is further evidence that the incongruent information is not the focus of attention due to the referential object.

Additionally, that the relevant stimulus properties received a benefit in such a spatial task suggests that the translation stage of information processing is more efficient when there is a referent object than when there is not. Thus, the endogenous control of attention was benefited by referential objects. This reduction was due to faster responding in the incongruent trials when the hands were located between the stimuli compared to when the hands were located below the stimulus.

Experiment 2 replicated the critical finding from Experiment 1: The goal is able to be prioritized when a referential object is located between the visual spaces on which a target can appear. It extends the results by demonstrating that the critical aspects of the effects – the reduction in the interference – occurs for non-biological references. Thus, the properties of the stimulus that are relevant to the goal are highlighted by the introduction of a physical object that is situated in a way in which the required actions have meaning relative to the object provided. Even though the hands produced a greater reduction, this was also accompanied by a larger overall Simon effect for the hands-experiment: This can account for the larger overall reduction. Hence, this result in particular is against the biological properties of the hands hypothesis, for which there should be no effect of a wooden referential object. Thus, the explanation that fits best with the given pattern of results is that the stimulus itself is receiving benefit from the referential object such that the translation process of assigned property left or right response is benefited by a referential object being located between the object, such that an action would occur to the left or to the right, to prioritize the goal.

EXPERIMENTS 3 AND 4: THE SRC TASK

In the SRC task, different instructions determine the mapping as compatible or incompatible. Thus, one is to respond to the location of the stimulus and remember the mapping rule s/he must use to decide the appropriate response (same - compatible/opposite - incompatible). Any prioritization realized as a function of the hands would indicate that participants have an ability to use stimulus location as a cue for responding correctly. In this case, compatibility is a between-blocks, relevant variable, rather than an irrelevant information variable as in the other experiments. Hence, this experiment allows determination of the extent to which one is able to prioritize a task goal rather than a stimulus feature.

This distinction is important for determining the specific conditions for which there will be an effect of the hands as well as offering a theoretical replication of Murchison and Proctor's (2015a) target-outside conditions in which the target-location rule needed to be remembered. Additionally, this experiment gives an indication as to whether processing differs for cases in which one is to make a spatially incompatible response to a stimulus compared to instances in which one has no prior knowledge of whether the spatial relation will be compatible or incompatible. Murchison and Proctor (2015a) demonstrated that participants are able to prioritize the space with regards to a rule that they need to remember for responding. However, this rule was unrelated to the spatial compatibility/incompatibility of the stimulus. Thus, to understanding how the hands affect processing of stimuli, it is critical to vary specifically the extent to which participants have prior knowledge of the compatibility condition they are currently performing.

Said another way, the SRC task is one in which the goals, as determined by the instructions, are directly tested. In Murchison and Proctor (2015a), emphasis was placed on the instructions being critical for this phenomenon, indexed by the targets located in the peripheral positions in a flanker-like task a similar pattern of results as the traditional flanker task with a centrally positioned target stimulus. Therefore, in order to determine if the referential-object explanation was correct in those previous studies, the SRC task was adopted here. This is a critical manipulation because the goal of this dissertation is to determine the likely mechanism that is leading to a reduction in interfering information in the presence of the hands. Thus, determining the extent to which the goal is prioritized is crucial.

By repeating the same manipulations in two experiments, the SRC task demonstrates the extent to which a goal is prioritized above and beyond the biological properties of the hands. Experiment 4 will repeat the exact methodology from Experiment 3, with the exception that the hands were replaced by the wooden-block barrier used in Experiment 2. As in Experiments 1 and 2, by replacing the hands with the wooden block as the object segmenting the space, this manipulation directly tested the alternative hypothesis that there is something unique about hands' abilities to control the orientation of attention.

When comparing across experiments, the hypothesis is that the task will demonstrate the critical differences between a hand-referent and artificial-referent. If any differences occur that are implicated in the critical interaction between referent-location and compatibility, this will be taken as evidence that the biological properties of the hands are indeed critical. However, if that pattern remains consistent, then the general hypothesis that a referent object which is spatially presented is able to assist in the goal, this will lead to a reduction in the interference by way of appropriately directed attentional resources.

Experiment 3: SRC Task With Hands as Barriers

Method

Participants. Participants were 32 new undergraduate students from the same participant pool as in Experiments 1 and 2. All had normal or corrected-to-normal vision.

Apparatus, stimuli, and procedure. The experiment was conducted similarly to Experiment 1, except as noted. The stimuli were purple circles 11-cm diameter (9.3° visual angle), shown on a white background on the monitor screen, at a left or right location that will be 11.8 cm (10°) from the screen center to the circle center. As before, participants input their responses using two foot pedals, one positioned below each foot.

The experiment was conducted in two blocks, counterbalanced for order. For half of the participants, instructions in the first block indicated that they were to make responses that corresponded to the stimulus locations: A right stimulus required a right response, while a left stimulus required a left response. Instructions presented on the screen read: "Please respond with the foot pedal on the same side as the stimulus". There were 72 trials in this block of the experiment. After completion, participants completed a second block in which they were instructed to make the response at the location opposite that of the stimulus for another 72 trials: A right stimulus required a left response, and vice versa. Instructions read: "Please respond with the foot pedal on the opposite side as the stimulus". The other half of participants completed the blocks in the opposite order. Before each block, 15 practice trials were administered. A between-subjects manipulation of stimulus-to-hand relation varied whether a participant was to perform with the hand held in the normal position or with the hands flipped such that the palm faced in the opposite direction. This was completed for left and right hands.

Stimuli remained on the screen until a response was registered, and feedback was given afterward: for incorrect trials, “Incorrect!” appeared in the upper left hand corner of the screen in red ink for 300 ms; for correct trials, “Correct!” appeared in the same location in blue ink for 300 ms. After that, there was a 200-ms delay prior to the next trial.

Results

As in Experiments 1 and 2, outliers (2.5% of trials) in the RT data were determined using the criteria applied by Davoli and Brockmole (2012). A 2 (hand placement: hand-between or hand-below) × 2 (compatibility: same - compatible or opposite - incompatible) × 2 (Stimulus-to-hand relation: palms or back of the hands) ANOVA with repeated measures on all factors was performed separately for RT and PE.

Reaction time. The ANOVA (see Figure 7) revealed longer RT for the hand-below condition (*M* = 565.5 ms) compared to the hand-between condition (*M* = 531.5 ms), $F(1, 31) = 4.55$, $p = .041$, $\eta_p^2 = .128$. There was a main effect of compatibility, $F(1, 31) = 27.58$, $p < .001$, $\eta_p^2 = .308$, because of the overall longer RT with the incompatible mapping (*M* = 572 ms) compared to the compatible mapping (*M* = 521 ms). The interaction between hand placement and compatibility was significant, $F(1, 31) = 19.55$, $p < .001$, $\eta_p^2 = .840$, reflecting a smaller compatibility effect for the hand-between placement (CE = 21 ms) than for the hand-below placement (CE = 89 ms). This was due to the incompatible trials showing a significant reduction in RT in the hand-between condition compared to the hand-below condition (*M* difference = 68 ms), $F(1,31) = 4.56$, $p = .041$, whereas the compatible condition did not (*M* difference = 0 ms), $F(1, 31) = 0.82$, $p = .30$.

With regard to palms versus the backs of the hands, there was no significant effect, *Fs* < 2.85, *p*s > .102.

Percent error. The ANOVA revealed a significant main effect of compatibility, $F(1, 31) = 4.28$, $p = .047$, $\eta_p^2 = .121$, with incompatible trials (*M* = 2.2%) responded to less accurately overall than compatible trials (*M* = 0.7%). There was no main effect of barrier, $F(1,31) = .79$, $p = .382$. No other effects were significant, *Fs* < 1.552, *p*s > .222.

Experiment 4: SRC Task With Wooden Blocks as Barriers

Method

Participants. Participants were 32 new undergraduate students from the same participant pool as in Experiment 1. All had normal or corrected-to-normal vision.

Apparatus, stimuli, and procedure. No changes were made in the methodology from Experiment 3, except to replace the hand on the display screen with a wooden block. Participants were instructed to keep the hands in their laps and maintain that position throughout the entirety of the experiment. Hence, the experiment is a 2 (wooden block placement: block-between or block-below) × 2 (compatibility: same - compatible or opposite - incompatible). The same block that was used in Experiment 2 was again utilized in this Experiment.

Results

Reaction time. The ANOVA revealed a difference due to block placement, $F(1, 31) = 6.61$, $p = .015$, $\eta_p^2 = .176$, due to longer RT overall for the block-below condition ($M = 630.5$ ms) than for the block-between condition ($M = 616$ ms). There was also a significant main effect of compatibility, $F(1, 31) = 126.53$, $p < .001$, $\eta_p^2 = .803$, with incompatible mapping ($M = 765.5$ ms) yielding longer RT than the compatible mapping ($M = 698.5$ ms). Finally, the interaction between block placement and congruency, $F(1, 31) = 25.04$, $p < .001$, $\eta_p^2 = .447$, mimicked the hands-as-barrier conditions (Experiment 3): The compatibility effect was smaller in the block-between placement (CE = 33 ms) compared to the block- below placement (CE = 101 ms). This was due to the incompatible condition, $F(1,31) = 1.51$, $p = .058$, and not the incompatible condition $F(1,31) = 1.08$, $p = .376$. No other effects reached significance, $Fs < 1$ (see Figure 7).

Percent error. The ANOVA revealed a significant main effect for block location, $F(1, 31) = 7.18$, $p = .012$, $\eta_p^2 = .188$, with fewer errors overall for the block-between condition ($M = 1.1\%$) than for the block-below condition ($M = 2.1$ %). There was also a significant main effect of compatibility, $F(1, 31) = 8.10$, $p = .008$, $\eta_p^2 = .207$, with a higher error rate for the incompatible mapping ($M = 2.3\%$) than for the compatible mapping ($M = 1\%$). Finally, the interaction between compatibility and block-placement condition was < .10 but > .05, $F(1, 31) = 3.22$, $p = .082$, $\eta_p^2 = .094$, reflecting a trend for a reduced compatibility effect in the block-between condition (CE = 0.4%) compared to the block-below condition (CE = 2.1%). No other effects reached significance, *Fs* < 1.

Between-experiment comparison. As for Experiments 1 and 2, an additional 2 (Barrier) × 2 (Compatibility) × 2 (Experiment) ANOVA compared the analogous effects between Experiments 3 and 4 for the SRC task to determine whether the effects of the hands and blocks differed. For RT, the main effect for barrier placement reached significance, $F(1, 60) = 5.54$, $p < .022$, $\eta_p^2 = .080$, because the barrier-between condition yielded faster responses than the barrier-below condition overall. The compatibility effect was significant, $F(1, 60) = 16.50$, $p < .001$, $\eta_p^2 = .205$. Notably, the compatibility × barrier-placement interaction was also significant, $F(1, 60) = 7.37$, $p = .009$, $\eta_p^2 = .103$, showing that the compatibility effect was modulated by presence of a referential object, be it a hand or wooden block.

No interactions with experiment were significant, with the most important nonsignificant difference being the 3-way interaction of experiment × barrier placement × compatibility, $F < 1.0$. Although the reduction in SRC effect from barrier-below to barrier-between conditions did not differ significantly between Experiments 3 and 4, the reduction was numerically larger in the former experiment than in the latter. This pattern, which is similar to that for Experiments 1 and 2, is due to the larger base

SRC effect in the hand-below condition of Experiment 3 than the block-below condition of Experiment 4.

The comparison with the PE data revealed a significant effect of barrier placement, $F(1, 60) = 4.18$, $p = .047$, $\eta_p^2 = .062$, such that PE was less for between barriers than for below barriers. Experiment interacted with barrier placement, $F(1, 60) = 7.83$, $p = .007$, $\eta_p^2 = .112$, such that this effect was larger for below barriers. Additionally, the compatibility × experiment effect was significant, $F(1, 60) = 8.13$, $p = .006$, $\eta_p^2 = .116$, such that the compatibility effect was larger in Experiment 3 compared to Experiment 4. This is a very unnatural position, which may lead to the slower responding, and hence the greater overall compatibility effect because attention is on the unnatural positioning. Critically, the barrier × compatibility interaction was significant, $F(1, 60) = 4.27$, $p = .043$, $\eta_p^2 = .064$, demonstrating the same pattern of reduced compatibility effect for between barriers compared to below, and the 3-way interaction between experiment, barrier, and compatibility was not significant, $F(1, 60) = 0.62$, $p = .434$. No other effects reached significance, *Fs* < 1.

Discussion

The critical analyses included the main effects of each factor of interest and the interaction between compatibility and hand placement. Evidence was analogous to that which was found previously and indicates that the hands are able to provide some means of directing attentional resources appropriately. Analysis of the interaction in terms of the relationship of the stimulus relative to the hands (at the back of the hands or at the palms) revealed this is not due to the biological properties of the hands (bimodal neurons being more concentrated at the palms versus a referential object).

Additionally, the 3-way interaction was not significant, which indicates that the palms are not unique in attentional capture. Combined, this evidence goes against a hypothesis citing the biological properties of the hands as the most critical mechanism.

Like the Simon or flanker tasks, hands or artificial blocks do reduce the impact of a goal, which is opposite to an automatically evoked response, dictated by stimulus location. Because the compatibility relations in an SRC task are instruction-based and not based on an irrelevant stimulus dimension, the results of this study show an overall benefit of attention due to a referential object. Therefore, this study is fundamentally different from all the others due to the compatibility being instruction-based and not mapping-based. As in the other experiments, the source of interference is analogously translated. Thus, the results of this study show an overall benefit of attentional control and implicated exogenous control in addition to endogenous control.

EXPERIMENTS 5 AND 6: THE MODIFIED STROOP COLOR-IDENTIFICATION TASK

When reading words, participants can attend and respond to the print itself or the color of a bar to determine the response to be executed. This experiment was executed much like the flanker task in which the segmentation of the space (by hands or wooden blocks) is into three distinct spaces in which the participant is instructed to the appropriate location. If similar results are revealed, the participants would demonstrate an ability to ignore automatic processing of words to facilitate their responding to relevant target stimuli. The reason to include a Stroop-task is that it is a demonstration of top-down processing influencing the responding through the relative automaticity of reading words. Thus, in order to determine how this effect pertains to processing of word stimuli, which overlap conceptually with the target color stimulus, but do not overlap physically, a Stroop-type task is necessary. This is not able to be ascertained from the other experimental types because the Stroop task includes reading processes and knowledge that cannot be suppressed.

Experiment 6 repeated the methodology from Experiment 5, with the exception that the hands were replaced by the wooden-block barrier used in Murchison and Proctor (2015 a, b). However, the distracting information is highly salient as the words have meaning to participants in addition to color having a mapping for the task. If there is something unique to the hands that they are able to better orient attention over an artificial barrier, this will become evident when comparing the results between Experiments 5 and 6. If there is no significant between-experiment difference, this is evidence that the hands are a serving as a referential object for intentional control of attentional resources.

Thus, this is a critical manipulation in determining the likely mechanism and the role of attention, which was demonstrated to be critical in previous studies as well as the Stroop dilution effect. The interpretation is such that the referential object(s) are used to orient attention appropriately and the goal relating to the spatial features of the task is highlighted. It was hypothesized that if it is determined that results are similar across Experiments 5 and 6, then there will be evidence that the word stimuli are not awarded attentional resources in barriers-between condition compared to the barriers-below conditions. This manipulation in particular will demonstrate this as the word meanings are not able to be suppressed, according to interpretations of the Stroop effect (Stroop, 1935; reprinted Stroop, 1992).

Experiment 5: Stroop Task With Hands as Barriers

Method

Participants. Participants were 32 new undergraduate students from the same participant pool as in all previous experiments. All had normal or corrected-to-normal vision.

Apparatus and stimuli. The methodology for this experiment was that used in Murchison and Proctor (2015a), modified for Stroop-like stimuli, but with participants holding their hands straight, with no curvature, as in experiments 1 and 3, previously.

This methodology was selected in order to make comparisons to previously reported results to determine if a comparable pattern of exists; in so doing, a greater understanding of the specific circumstances hands affect processing in otherwise comparable situations can be developed. The target stimuli were color bars (.5° wide × 3.7° high) assigned to specific responses at the beginning of the experiment. These targets were accompanied by the distractor words: PURPLE, ORANGE (Color words: each letter: 2.2° wide × 3.7° high) on a dark gray background, which serve as distractors. Each of these was the matching color (congruent trials) or the mismatching color (incongruent trials; modified from Melara & Mounts, 1993).

The colors were assigned to responses at the beginning of the experiment. Purple and orange targets were assigned to left and right foot press responses, counterbalanced across participants. There were separate blocks in which the color words were presented either at fixation or in the peripheral location in order to have targets appearing in the center of the screen between the palms of the hands or at the outer location toward the back of the hands. This aspect was counterbalanced for order; color bars that served as targets appeared in the opposite location of the color words (at the peripheral location or centrally located).

For the outside-target condition, color bars were located at the periphery (7.7 cm or 15° visual angle separation from the centrally located target), one to the left and one to the right, with the distractor word located at the central location of the monitor. For the inside target condition, two instances of the color word (each letter; 5.0° wide × 9.0° high) appeared at a 7.7 cm (15° visual angle) separation from the centrally located color bar that is the target. Responses were made by pressing a left or right foot pedal, connected to the computer through a serial-response box, with the corresponding foot.

Procedure. Prior to beginning, the experimenter explained the general instructions and demonstrated the appropriate hand placements for both of the trial blocks in the experiment: hands around and hands below. Instructions, which indicated where the participant would hold his/her hands and the mapping of the letters to responses, were displayed on the computer screen before each block. For each participant, the inside and outside target conditions were completed in separate halves of the experiment, counterbalanced for order across participants. Within each half, hand location, around or below, was counterbalanced. Each block contained 72 trials (36 each of congruent and incongruent trials), for which order was randomized. In the hands-around block, participants held their hands directly around the location in which the target letter would appear, which was the center of the screen. Each hand was located 5.7 cm away from the target letter. In the hands-below conditions, participants held their hands in the same vertical position, but located below the screen at the "Dell" symbol. Participants were told which stimuli were assigned to the respective responses, and this assignment remained constant throughout the experiment.

The study used a 2 (hand location: between versus below) × 2 (congruency: congruent versus incongruent) × 2 (stimulus-to-hand relation: palm versus back of the hand) design. Prior to each block of experimental trials, 10 practice trials (5 each of congruent and incongruent) were given to make sure that the participants understood the instructions for that block. In addition, the experimenter remained in the room for the duration of the session, seated in a corner located behind the participant, to ensure that the participant's hand positions will remain constant.

Participants input their responses to the identity of the target using the two foot pedals, one positioned below each foot. Order of the blocks was counterbalanced across participants such that half of the participants performed the around condition followed by the below condition, and vice versa for the other half of the participants. They were told to respond as quickly and accurately as possible. Stimuli remained on the screen until a response was registered, and feedback was given afterward: for incorrect trials, "Incorrect!" appeared in the upper left hand corner of the screen in red ink for 300 ms; for correct trials, "Correct!" appeared in the same location in blue ink for 300 ms. After that, there was a 200-ms delay prior to the next trial.

Results

Outliers in the RT data were determined as in the prior experiments (2% of trials). Participants making more than 20% incorrect responses were replaced (No participants fell within this criterion). A 2 (hand placement: hands-between or hands-below) × 2 (congruency: congruent or incongruent) × 2 (Hand direction: palms facing inward or crossed hands/palms facing outward) ANOVA with repeated measures on both factors was performed separately for RT and PE.

Reaction time. The ANOVA (see Figure 8) revealed a trend toward a difference between hand-placement conditions, $F(1, 31) = 3.65$, $p = .065$, $\eta_p^2 = .105$, due to longer mean RT for the hands-below condition (M = 855.5 ms) than for the hands-between condition (M = 819 ms). There was also a main effect of congruency, $F(1, 31) = 34.27$, $p < .001$, $\eta_p^2 = .525$, with responses being slower on incongruent trials (M = 855 ms) than on congruent trials (M = 819.5 ms). Finally, the interaction of hand placement × congruency, $F(2, 60) = 30.35$, $p < .001$, $\eta_p^2 = .495$, revealed that there was a significant reduction in the Stroop effect with the hands-between placement (CE = 4 ms) compared to the hands-below placement (CE = 67 ms). No other effects reached significance, $Fs < 2.92$, $p = .1$.

The evaluation with regard to palm-specific effects, revealed a significant hand-direction × barrier interaction, $F(1, 31) = 22.6$, $p < .001$, which was due to a faster RT when the palms faced the target for between conditions. No other effects reached significance, $Fs < 2.49$, $ps < .120$. Thus the palms do not impact one's ability resolve conflict, which is the critical interaction.

Percent error. The ANOVA revealed a trend for barrier location, $F(1, 31) = 3.59$, $p = .067$, $\eta_p^2 = .101$, with fewer errors overall for hands-between conditions (M = 0.9%) than for hands-below conditions (M = 2.4%). There was a main effect of congruency, $F(1, 31) = 4.31$, $p = .046$, $\eta_p^2 = .119$, with incongruent trials (M = 1.9%) responded to less accurately overall than congruent trials (M = 1.4%). No other effects were significant, $Fs < 1$.

Experiment 6: Stroop Task With Wooden Blocks as Barriers

Method

Participants. Participants were 32 new undergraduate students from the same participant pool as in Experiment 1. All had normal or corrected-to-normal vision.

Apparatus, stimuli, and procedure. No changes were made in the methodology from Experiment 5 except to replace the hands on the display screen with wooden blocks. Participants were instructed to keep the hands in their laps and maintain that position throughout the entirety of the experiment. The two blocks that were utilized in this study were of the same size and shape as has been described in Experiments 2 and 4. They were placed in the analogous around and below conditions as were described in Experiment 5, and the hands were to be placed in the laps of the participants while they administered their responses.

Results

Reaction time. The ANOVA (see Figure 8) revealed a congruency effect, $F(1, 31) = 4.43$, $p = .043$, $\eta_p^2 = .125$, with incongruent trials ($M = 765.5$ ms) being responded to slower overall than congruent trials ($M = 699$ ms). There was a significant interaction, between block placement and congruency, $F(1, 31) = 5.89$, $p = .021$, $\eta_p^2 = .160$, revealing a reduction in interference as indicated by a smaller Stroop effect for the blocks-between placement (CE = 33 ms) than for the blocks- below placement (CE = 101 ms). Critically, the three-way interaction between the target, block placement, and congruency was not significant, $F = 1.74$, $p = .197$, thus the critical interaction between barrier and congruency was not a by-product of the target locations.

Percent error. There was a significant effect of congruency, $F(1, 31) = 4.28$, $p = .047$, $\eta_p^2 = .121$. No other effects reached significance, $Fs < 2.79$, $p > .105$.

Between-experiment comparison. An additional 2 (Barrier) × 2 (Congruency) × 2 (Experiment) ANOVA compared the analogous Stroop effects between Experiments 5 and 6 to determine if the effects were comparable. The barrier placement × experiment interaction reached significance, $F(1, 60) = 8.02$, $p = .006$, $\eta_p^2 = .115$, because difference in the barrier effect was larger for wooden blocks compared to hands. Similarly, the congruency × experiment interaction was significant, $F(1, 60) = 4.45$, $p = .039$, $\eta_p^2 = .067$, because the congruency effect was larger in Experiment 6 than in Experiment 5. Notably, the congruency × barrier placement interaction was significant, $F(1, 60) = 6.69$, $p = .012$, $\eta_p^2 = .097$, but the 3-way interaction between experiment, barrier placement, and congruency was not, $F(1, 60) = 1.03$, $p = .314$, showing that the Stroop effect was modulated by the presence of a referential object, be it hands or artificial blocks. No other effects reached significance, $Fs < 1$.

The only significant effect that was revealed when evaluating the PE data was that of congruency, $F(1, 60) = 6.76$, $p = .012$, $\eta^2 = .097$.

Sequential effects analysis. An analysis of sequential effects was performed analogous to that for Experiments 1 and 2 with a repeated-measures ANOVA, with factors of barrier type (hand versus wooden block), barrier location (between versus below), current trial congruency (congruent or incongruent) and previous trial congruency (congruent or incongruent). There was a significant CSE, $F(1, 60) = 4.87$, $p = .039$, $\eta_p^2 = .188$, reflected in a larger congruency effect following congruent trials (CE = 14 ms) than following incongruent trials (CE = 6 ms; see Figure 9). Results indicated a similar trend towards an interaction between CSE and barrier location, $F(1, 60) = 3.10$, $p = .080$, $\eta_p^2 = .067$: The CSE was larger when the barriers were located below the stimuli (CSE = 38 ms) rather than between them (CSE = 30 ms). However, the CSE did not interact with barrier type alone, $F(1, 60) = 1.42$, $p = .247$, or in combination with barrier location, $F(1, 60) = 1.18$, $p = .29$.

Discussion

Evidence from this study supports that from the Simon task of Experiments 1 and 2 as well as the flanker task studied by Murchison and Proctor (2015a, b): The barrier × compatibility interaction revealed that incongruent trials are reduced in the presence of referential objects. Additionally, sequential effects implicate general attention being benefited due to the reduced CSE when there is a referential object: be it hand or wooden block that segments the display compared to instances when it does not. As in the Simon task, as well as prior evaluations of the flanker task (Englert & Wentura, 2016), this finding suggests that the intruding information is not attended to, and hence contributes to neither the compatibility effect nor the CSE for any form of referential object.

Moreover, this study also established that even highly salient and meaningful information, word definitions, can be inhibited or ignored more effectively as a consequence of a referential object. That is, the conflict produced by relatively automatic processing is reduced in the presence of a referential object. Thus, wooden blocks and hands as barriers seem to provide a starting point for attentional resources whereby the irrelevant information is not attended to and, consequently, not processed. Additionally, for artificial blocks, when the targets appear outside of the hands rather than inside, the compatibility effect is larger and responding is longer overall.

Overall, the responding across conditions took longer when participants were to move their attentional resources from fixation to the outside to make a response, and this exacerbated the interference effect as well. Thus, this result suggests that responding away from center overall takes longer, which is not surprising because having to divert attentional resources would cause longer overall responding. Although, this result was not found in the hand condition, it does not change the overall interpretation of the critical nature of referential objects, as the three-way interaction was not significant, and fits in with previous findings of the effect.

A critical note to be made about the wooden blocks that were used in this study is they differed from those employed in Murchison and Proctor (2015a, b) for which the blocks were larger and were curved in order to match the contours of an adult-male hand. Comparing the results from this experiment to those reported in the prior flanker-task studies demonstrates a consistency that is critical to highlight, as the blocks here are far less substantive and do not mimic the human hands' contouring. This not only demonstrates cross-modal verbal interfering with the nonverbal information, but also shows generalizability across referential objects, which move even further away from a hand resemblance. This finding is, hence, an important replication of the prior work.

An absence of effect of hand position provides evidence that the biological properties of the hands are not the most likely mechanism. That particular hypothesis argues that there will be faster responses only when stimuli are presented within the palm space due to greater density of bimodal neurons for that area. However, the critical relationship was not the relation to the palms but rather the hands serving as referential objects.

GENERAL DISCUSSION

All tasks used in this group of experiments and the prior ones reported by Murchison and Proctor (2015a, b) come from the compatibility literature, in which correspondence effects between stimuli and responses and between relevant and irrelevant stimulus dimensions are examined, but each focuses on different aspects of information processing. By considering hand-specific effects across experiments, it can be determined in what ways the hands affect attentional prioritization, and if this effect is unique compared to other referential objects. The combination of the experiments leads to a proposed mechanism of referential coding across response-selection tasks in which conflict must be resolved. In addition to conflict, the stimulus-response relationships are spatial, and any reference is meaningful to the spatial responses to be made.

In all the tasks, the participants were to administer their responses using foot-press responses in order not to confound the response location with the hand postures, which varied across experimental conditions and across the studies. The strength of this group of experiments lies in the methodological differences across the tasks, each with its own unique properties. That is to say, the study allowed a detailed investigation of segmenting-referential objects across response-selection tasks.

However the means by which a response was selected differed. The group of experiments allow for evaluation of the effect, comparing:

(1) when there is 1 object (Simon and SRC) versus 2 objects (Stroop) segmenting the space;
(2) when the location information is relevant (SRC) versus when it is not (Simon and Stroop);
(3) when relevant information occurs at fixation (Stroop) versus when it can only occur to the outside (Simon and SRC);
(4) whether the source of incongruency is a separate stimulus within the visual array (Stroop) or part of the stimulus itself (Simon and SRC – incompatible trials).

Across the tasks evaluated – Simon, SRC, and Stroop tasks – along with previous studies of the flanker task (Murchison & Proctor, 2015a, b), there was a consistent reduction in interference from incongruent/non-congruent trials in spatial compatibility tasks. This was the case when the reference object meaningfully segmented space so the spatial features of match the spatial responses to be made. That is to say, according to the results across experiments, the critical relationships are those that meaningfully organize the space with the participants' goals of the task. In this way, the ability of the hands or other objects to organize the visual space translates into better overall performance across response-selection tasks. Additionally, this reduction occurs when the stimulus dimensions themselves determine the spatial relationships, as well as when the spatial organization is more important. Thus, both the endogenous and exogenous control of attention are benefited by salient referential objects. Finally, all the tasks share response-selection processes.

A notable difference occurred, however, in that the pattern is not mirrored between the Simon and SRC tasks compared to the Stroop (and prior flanker versions). This difference is due to the fact that in the Simon and SRC tasks, when one hand segments the space, the wooden block conditions show a smaller reduction in the congruency effect. In the Stroop task, the wooden-block conditions had larger reductions in the congruency effect overall. Interestingly, in both Murchison and Proctor (2015a: hands-around = 7 ms difference versus hands-below = 22 ms difference; wooden blocks-around = 15 ms difference versus wooden blocks-below = 34 ms difference) and (2015b: hands-around = 13 ms difference versus hands-below = 22 ms difference; wooden blocks-around = 16 ms difference versus wooden blocks-below = 35 ms difference), this was the case.

That is to say, when there are two referential objects that segment visual space, the reduction seems to be larger overall in artificial-barrier conditions; in contrast, when only one referent is available, the reduction is larger for the hands. This may be due to the presence of one versus two referential objects, or to multiple stimuli in the visual array. In both the Simon and SRC tasks, only one stimulus is present and is located to the left or to the right, which could more meaningfully map to left/right hand. In the Stroop and flanker versions, there are three stimuli separated by two barriers.

Prior Flanker Experiments

In Davoli and Brockmole (2012) and later, Murchison and Proctor's (2015a, b) studies, a modified flanker methodology was employed such that the stimuli and distractors were separated in the visual array, and there was a mapping of stimulus identity to response to be made. The unique feature of the flanker task is that stimuli (in this case, two letters) are assigned to left and right keypresses, and the target letter on a trial always occurs in a centered location. The irrelevant stimulus dimension is the simultaneous occurrence of instances of one of the letters in flanking positions. The flanker effect is that the letters in the irrelevant flanker positions slow responses when they are incongruent with the target letter. In Murchison and Proctor (2015a), participants were instructed to respond, in separate conditions, to the centrally or peripherally located target letters. They were to do so in conditions in which their hands were positioned between the target and distractor letters, or in conditions in which the hands were positioned below the screen, such that they did not separate target from distractor areas.

In Murchison and Proctor's (2015b) study, the same methodology was used, but participants had their hands crossed such that, when positioned on the screen, the right hand separated the left and center letters and the left hand the center and right letters, with the palm of each hand facing the outer letter on their respective sides. The combined studies evaluated the effect of the target location, as well as hand/back of palm effects. Specifically, the former study confounded palm position with target location, such that the palms were always located near the centrally located target letter and the back of the hands always nearest the peripherally located letter. The studies showed a reduction in the interference from incompatible flankers when the hands were in the around-posture compared to when they were located below the screen. This was the same when the targets were in the inside or outside condition and was replicated in the crossed-hand (2015b) scenarios. Thus, by comparing the two studies effects, it was established that the pattern was consistent across studies as well as that it replicated the prior Davoli and Brockmole (2012), from which the methods were adopted and the same reduction in interference was found.

More specifically, Murchison and Proctor's (2015a) experiments established that one could prioritize space relative to a referential object based on instructions that indicated where attentional resources would need to be directed: inside or outside of the hands. Critically, the palm/back of the hand distinction had no bearing on the critical relationships with compatibility in the prior experiments, thus the current experiments provide further evidence palm-hand space is not unique in impacting attention across compatibility tasks.

Simon Task

Simon Task With Hands and Blocks as Referential Objects

In Experiment 1, the Simon task was used to determine under what conditions a referential object was able to prioritize specific properties of a stimulus. In this task, the relevant dimension was the color of the stimulus. In contrast to the flanker task, in the Simon task there are no irrelevant stimuli adjacent to a relevant target stimulus, and the correspondence effect is based on the relation between the irrelevant stimulus location with the response location. The hands cannot be used to separate a relevant region of the screen from two other regions defined as task-irrelevant, but they can partition the screen into two regions in which a target stimulus may occur. Thus, the method was modified to have a single hand on the screen that separated the display into two halves. The findings from Experiments 1 and 2 demonstrated similar results to the flanker task, in that the Simon effect was reduced when a hand was placed on the screen as opposed to when one was not. This result implies that the hand reference can serve to restrict processing of the location associated with a relevant stimulus in addition to restricting processing of items in regions of space that are known in advance to contain irrelevant stimuli.

Results from the Simon tasks suggest that activation of the corresponding response by the physical location of the stimulus can be overcome. This evidence strengthens the finding from previous experiments from which this methodology was developed (Davoli & Brockmole, 2012; Murchison & Proctor, 2015a). These prior studies indicated a similar reduction in interference from incongruent trials across tasks. Thus, not only are the hands able to prioritize the physical space but also the properties of the stimulus itself.

Relation to Other Work: Semantic/Numeral Stimuli

One study looking at the Simon task sought to reveal a difference in stimulus type, determining if the mechanism for semantic/numeral stimuli was different from that of color stimuli (Liepelt & Fischer, 2015), due to divergent results between the two stimulus types in prior studies (bottom-up processing as critical, e.g., Reed et al., 2006, versus top-down processing as critical, e.g., Garza, Strom, Wright, Roberts & Reed, 2013). In Liepelt and Fischer’s Experiment 1, participants were to categorize numerals which could occur to the left or the right of the screen as less than or greater than five, with numbers 1-4 being assigned to a left keypress response and 6-9 assigned to a right keypress response. Participants completed this task in two different postures, one in which the hands were positioned around the computer screen and the other in which the hands were located away from the screen. Results demonstrated a larger Simon effect in the hands near posture, which led the authors to directly manipulate the categorization in Experiment 2.

Experiment 2 utilized the same methodology, but the numeral stimuli were colored. In the color version of the task, participants were to respond to the color of the numeral presented, which was mapped to a left or right response; in the semantic version of the task, participants made the same numeral judgements with the same categorization as in Experiment 1. For the color trials, there was no reduction in the congruency effect which did occur for the numeral trials when the hands were located at the monitor versus when the hands were placed on the knees.

When making judgments about a number, the smaller numbers being physically nearer to the left hand and larger numbers to the right hand creates a correspondence effect [the SNARC (Spatial-Numerical Association of Response Codes) effect; Dehaene, Bossini, & Giraux, 1993]. Thus, having the hands visible provides a salient a meaningful object for counting, which could reduce the RT for the incongruent trials. However, it does lead to the possibility that the hands located to the outside are unique in their impact in the numerical Simon task. Future studies could vary the hands versus artificial blocks at those positions in order to determine if this is the case. It may also be the case that the results obtained are due to the hands not meaningfully segmenting the visual space into left/right responses. Both hypotheses require further investigation as to why the semantic Simon effect was dissimilar from the color version.

At face value, Liepelt and Fischer's (2015) results seem contradictory to the current study. However, the pattern of their results generally fits with the results from the present Experiments 1 and 2 for the following reason. The locations of the referential objects are such that they would be meaningful to the responses that were to be made. Having hands visible to the side of the space does not meaningfully segment it into left/right responses for the color stimuli, such as the centrally-located referential object provided to the participants in this study, but it does provide meaning to the semantic/numeral stimuli.

This was shown to be the case by Murchison (2013) in a flanker-like task. Participants were to respond to a centrally located letter, with compatible, incompatible, or neutral distractors located on either side. This was performed for conditions in which the hands were placed around the targets and the distractors, or at a location below the visual array, but maintaining the vertical separation of the hands. The results revealed there was no reduction in the interference effect. When the same vertical separation of the hands was employed, but the hands separated the visual space of the targets from the spaces of the distractors, the reduction in the interference occurred. Thus, the location of the referential object, and how it relates to the response to be made is paramount to impacting performance.

Hence, the reduction in the Simon effect for numeral stimuli that was not present for the color stimuli generally fits with the hypothesized mechanism offered in this referential coding account. Consequently, Liepelt and Fischer's (2015) study suggests that the referential object must be meaningful to the responses being made – hence, the goal – and generally agrees with a referential coding account if the hands are considered an object to aid in counting; which they frequently are.

Similar results were demonstrated by Wang, Du, He, and Zhang (2014). Four experiments employed a Simon task, and four response positions were tested. The first required participants to respond using a left and right mouse attached to the sides of a computer monitor; this condition was compared to a one in which the mice were fixed to a wooden board put in the participants' laps. In another condition, the computer mice were located on the desk in front of the participants. In the final condition, the mice were situated on an apparatus which mimicked the horizontal placement of the mice in the first condition, but in a position that was in front of the computer screen; thus, the participants' hands were not located around the stimuli, but rather, in front of the stimuli. The authors reported a larger Simon effect for visuomotor stimuli when the hands were nearby compared to when they were not, which they interpreted to indicate a stronger mapping from stimulus to response near the hands. Critically, Wang et al.'s (2014) hand placements did not segment the display, but rather all of the visual information occurred within the hands, which means they could not be used as a left/right segmentation that corresponded to the left/right responses to be made. This could explain the contrasting results between the conditions.

SRC Task

SRC Task With Hands and Blocks as Referential Objects

The SRC task is unique in the way by which participants decide the response, and thus is very meaningful to the overall understanding of referential object effects such as these. Unlike the flanker and Simon tasks, the SRC task is driven by the instructions given. It is similar to the Simon task in that a single stimulus is presented in a left or right location on each trial. The difference is that in the Simon task, the stimulus location is irrelevant whereas in the SRC task the location defines which response is to be made. Results from the SRC task showed the same reduction in the compatibility effect when a hand or wood block served as a referent object in the between-barrier condition compared to the below-barrier condition. When looking at the hand-effects in more detail, it was also determined that it was not an effect of whether the stimuli were located near the palms or the backs of the hands. In conjunction with the wooden-blocks conditions, this result suggests that the referential objects' meaningful segmentation led to the reduction in the SRC task rather than something specific to the hands, or unique to the palms.

The similar effects for the single-hand/block placements used in Experiments 1 and 2 and Experiments 3 and 4 indicate that stimulus location is not driving the effect, but rather the relation between the goal and the referential objects, as they relate to the responses being selected. Thus, this experiment offers confirmatory evidence that the hands are able to be used as referential objects to prioritize response-selection rules over and above automatically processed physical location. This suggests that the referential object could be specific to the assignment of the instructed response properties one is to employ.

Hence, the goal is entirely deciding the compatibility between the stimulus location and the response to be made, rather than a physical feature of the stimulus itself. This was a critical manipulation, therefore, to determine if the prior experiments' findings were a result of the physical properties only, or if the goal is able to be prioritized also.

The two SRC experiments confirmed that the instructions are impacted by a referential object, when the object meaningfully segments the space such that responding is logically related to the referential object – the between position. When the referential object is below the visual array, this was not the case, which gives merit to the argument that the meaningful segmentation of the space by a referential object improves performance.

Relation to Other Work: Wheel Rotation Responses

A series of experiments relating hand posture to referential coding in an SRC task was conducted using wheel-rotation responses. Guiard (1983), Murchison and Proctor (2013), and Wang, Proctor, and Pick (2003) conducted experiments with the Simon task, for which stimulus location is irrelevant, and found that clockwise and counterclockwise wheel rotations were coded as right and left, respectively, unless the hands held the bottom of the wheel, in which case some participants appeared to code responses with respect to direction of hand movements. Notably, Wang et al. (2003) demonstrated similar results for Simon and SRC tasks which were also observed in this set of experiment.

Critically, Proctor, Wang, and Pick (2004) conducted an SRC experiment with wheel-rotation responses in which left or right tone location was relevant, and two different mappings of locations to clockwise/counterclockwise wheel rotation responses were used. Across Proctor et al.'s (2004) experiments, the hand location (top or bottom of the wheel) was manipulated as well as the instructed focus of attention. When participants were not instructed on where to focus attention, they did so in a manner which led to a compatible mapping of stimulus location and wheel rotation response (Experiment 1); this means that when the hands were located at the bottom of the wheel, subjects focused on the top of the wheel, which would lead to a compatible mapping and not on the hands.

This, specifically, is a critical finding, as accounts of hand-unique effects would make the opposite prediction, considering the hand as the dominant frame of reference across manipulations. However, when instructed to focus on either the hands or the wheel, they did so, even if that led to an incompatible mapping for the instructed reference frame (Experiment 2). This included a condition in which the wheel's rotation controlled a cursor-reference frame, which was to be the focus of attention (Experiment 3). The combined studies emphasize that instructions are able to vary one's frame of reference, even if not advantageous to responding, and the hands are not necessarily the dominant frame of reference.

Converging evidence can be found in Murchison and Proctor (2013) as there was not an effect of unimanual (one-handed) or bimanual (two-handed) manipulation of a wheel when the hands were located at the top, bottom, or sides, nor an effect of the hands. This suggests that the goals, by instructions, were highlighted above the hands, and frames of reference resulted from those goals.

The one caveat to such a referent is when the wheel is held at the bottom, for which there is evidence that the top of the wheel and the hands are both used as references (Proctor et al., 2004). Thus, for the SRC task, it seems that the reference that is most logically coded in terms of the responses to be made was the one utilized by the participants. This fits with the overall findings in this study as the hands and wooden blocks were both able to be utilized as referential objects, likely because they meaningfully segmented the display based on the responses to be given.

Stroop Task

Stroop Task With Hands and Blocks as Referential Objects

The Stroop effect was the final study, which is similar in many ways to the modified flanker task from Murchison and Proctor (2015 a, b), which is why 2-hand postures are utilized rather than a single hand, but includes important methodological differences. It uses color as relevant rather than form identity, the relevant and irrelevant information is in different codes (physical vs. verbal), and the verbal code is known to predominate. That is to say, the interference arises from the discrepancy between the word meaning and the physical color on incompatible trials.

By studying the Stroop effect, it was possible to determine that the word meanings, which are salient and meaningful distractors, are able to be ignored as well. In the Stroop task, it is known that the text definition is prioritized over other physical dimensions of a stimulus – even those that an alternative (i.e. color) would be able to be processed prior to determining the definition. In the Simon task, the more automatically processed dimension – location – was able to be more readily ignored due to the presence of hands in between space. This indicates that the organization of the space that is permitted by the referential objects does orient attention to the correct location, which allows the non-corresponding words not to be read and leads to a reduction of the interference from those distractors.

Relation to Other Work: Stroop Dilution Effect

The Stroop effect is reduced by half (depending on the details of the experiment) when a neutral word is added to the display, along with the target (Kahneman & Chajczyk, 1983). Results from my Stroop tasks are in agreement with the Stroop dilution effect, which has been used to describe the Stroop phenomenon in the presence of neutral words (Cho, Lien, & Proctor, 2006; Kahneman & Chajczyk, 1983). Cho et al. (2006) describe that the effect as due to a competition between the all the present stimuli and perceptual interference of the stimuli. When the target stimulus was also the word which had the relevant color dimension for responding, there was a larger Stroop effect compared to when the neutral word was the colored word. Thus, the competition is between words. Because the goal of the task requires responding to color, priority is given to the word that contains the color.

The attention capture account of the effect suggests that this phenomenon occurs because word recognition in involuntary and occurs serially (Van der Heijden, 1992). This model is characterized as unlimited capacity in early processing because this is when the distinction between the color bar, as the target, and the color word, as the distractor, is able to be made. The model suggests that parallel processing is not interrupted, but only occurs at a semantic level, which is why the model assumes unlimited capacity. According to Mitterer, La Heij, and Van der Heijden (2003), "In this model the function of attention is not to protect limited resources from an information overload. Instead, attention is necessary for the initiation of a response, given an identified stimulus" (p. 32).

The general results from Stroop dilution as well as this model are similar to the results found in the present set of experiments. In the present Stroop tasks, the color is present in a color-bar that is to be responded to and the distracting words are presented in a neutral color. In this scenario, there is a reduction in the Stroop effect from the presence of an extraneous item. If the available referential objects (extraneous items) are aiding in the selection of the color bar as the target in early processing, then the impact of the distracting words would be reduced, analogous to neutral words in the Stroop dilution effect. In other words, when the color-bar methodology of the Stroop task is used and the appropriate reference objects are present and segmenting the space, the color-bars are able to be prioritized in such a way that the distracting words are not selected as the focus of attention. Thus, this prioritization leads to the reduction of the interference in the between-barrier conditions.

Neuropsychological Arguments

Dorsal vs. Ventral Stream

The hypothesis which advocates the hands as unique has evidentiary support in the neuropsychological studies of sensory and motor systems that are activated in compatibility tasks. The evidence suggests there is activation of the motor system in conceptual processing as well as during perceptual processing. That there is activation during both processing types suggests that the body’s positioning and movement impacts response selection and not the response area itself. It is suggested that the distinction lies in the differential activation between the dorsal and ventral pathways, and is thus characterized as a dual-route model (Caligiore, Borghi, Parisi, & Baldassarre, 2010).

The aforementioned neurological evidence is in contrast to the behavioral data presented in these experiments. The results from this finding lend support to spreading activation between the conceptual, sensory, and motor systems, which is a disembodied account. Thus, the studies presented in the above experiments are in contrast to embodied cognition accounts of hand specific effects as they relate to the dorsal/ventral streams. That is to say, they lend support that the body is not uniquely able to be a frame of reference, but rather is one of a multitude of objects that can be utilized as such. However, it stands to reason that the motor activation may be associated after conceptual information and response selection has occurred, which would fit in with coding explanations of compatibility effects.

Magnocellular/Parvocellular Differentiation

A second alternative account is motivated by the dorsal/ventral distinction, and argues that magnocellular and parvocellular visual pathways lead to the hand-unique effects (for a review, see Goodhew, Edwards, Ferber, & Pratt, 2015). The magnocellular pathway has speeded responding for visual information near the hands while the parvocellular pathway has slowed responding overall due to high spatial acuity. Thus, the distinction suggests that stimuli near the hands recruit higher involvement of the former pathway, and in situations in which the hands are not able to facilitate responding, the latter pathway is contributing more.

Results from this study are also in opposition due to the analogous reduction in the compatibility effect across referential object types. As before, the neurological evidence suggests the distinction to be important, but the behavioral studies conducted above do not support the hypothesis in terms of the hand-uniqueness.

Palms Versus Backs of the Hands

Across all experiments, a consistent outcome was that the palm versus the back of the hand did not lead to differences in the size of the interference effect. One of the tenant hypotheses that has come out of the embodied cognition accounts with regards to the biological properties of the hand effects is that the reductions in the interference should be different for the palm-space of the hands due to the greater density of bimodal neurons for that area, or due to that area of the hands being more critical for living, established through evolutionary processes. Thus, the engagement of attentional resources to or from that area will be differentially affected as compared to other biological parts, or any other referent more generally, because it is the most unique part of the body for such processes. Across six experiments (eight if the effects from Murchison & Proctor, 2015, are considered as well), there was no evidence that the palm/back-hand distinction is not leading to any differences.

That this is the case when the physical properties of the stimulus are crucial for responding, nor when the goals defined through instructions are highlighted provides evidence distinguishing the hand space for response-selection processes is not crucial. This is a very important finding that has large-scale implications for areas of study that are popular today. There is a large body of literature looking at hand-specific and palm-specific effects as they relate to compatibility. Specifically, the mechanism by which responding is speeded due to the presence of the hands is studied frequently as it relates to object pictures, location of space of the object relative to the person, and the relationships of objects to the body. However, these Experiments directly test this hypothesis. The implication is that effects from hand-specific and palm-specific effects for compatibility in previous studies and in future studies should consider alternative hypotheses to the bimodal neuron/palm-specific accounts. This finding is the major theme and primary implication of this particular set of studies with a secondary implication being that the referential object, more generally, do affect response-selection processes. The exact mechanism requires further studies to rule out alternative implications discussed previously.

Relation to Embodied Cognition

The combined findings from this study relate to the greater literature on embodied cognition more generally. In that literature, there is a reported benefit for processing of information located by the hands compared to information that falls further from it (e.g., Reed et al., 2006; Reed et al., 2010). A notable finding is between extrapersonal space, for which a hand cannot be located, versus peripersonal space, in which the hands are able to benefit processing. This benefit was speeded responding in a compatibility-type experiment for which the congruency was decided by the side on which a handle appeared on an imaged object. In peripersonal space, there was a benefit in terms of a reduced compatibility effect compared to extrapersonal space (i.e., Ambrosini & Constantini, 2013; Coello et. al., 2008). However, with regard to previous study, extrapersonal space is not accessible for a referential object, thus one cannot said referential object to benefit responding. When a tool was introduced into the space, the benefit for responding reappeared. This was taken as evidence that the tool is an extension of the hand, and thus the biological properties of it benefit responding. However, a simpler explanation is the tool, much like the wooden blocks, is a referential object that benefits responding similarly to this set of experiments.

Similar arguments can be made for those findings in which there is a benefit for responding when one target falls nearer to a hand while the other falls further away. Reed et al.'s (2010) experiment included different hand postures, in which a palm was placed in a position to the outer location of a stimulus at the edge of a computer screen. Additionally, in the back-hand condition, participants placed a single hand at the center of the screen, separating the screen into two areas. The opposite hand would be making responses to the other side of the monitor. Results demonstrated a modulation of performance due to the hand position relative to the target such that when the palm side of the hand was near the target, detection responses were significantly faster than when the back side was. However, this was the position in which the hand as a referential object was useful for responding, since the relationship between the hands was confounded with response location. That is to say, the palm always faced the side of space that the responses were being made, thus overall show an effect such that the referential object benefited responding.

Thus, interpretation of results from prior studies benefits from a referential coding account such as this. When taking into account the relationship between a referential object and a response, alternative explanations can be offered for prior experimental findings that do not invoke uniqueness of the hands as a crucial factor.

SUMMARY OF MAJOR FINDINGS

From a theoretical standpoint, the combination of experiments described in this dissertation suggests that when space is meaningfully separated spatially, the goals, which are spatially defined, will be prioritized such that the task-dimensions relevant to that goal are prioritized. This prioritization was hypothesized to be the case in the current set of studies due to a reduction in flanker interference when participants were instructed to respond to a specific letter, while ignoring others, which was impacted by the presence of the hands in the visual space. In the flanker task, it was found that the goal was prioritized due to the presence of the hands or other artificial objects. Similarly, in the present case of the Simon task, the feature that was prioritized was the physical appearance of the stimulus, that being the dimension of color. In the SRC task and the Stroop tasks, the instructions are prioritized in terms of where the focus of attention should be in order to improve responding. This improvement was indexed by a reduction in the interference effect across studies, which is the metric used to determine the conflict in the response-selection processes in compatibility experiments.

Furthermore, and most critically, the reduction of interference occurred for both hands and artificial blocks (in the form of wooden blocks). When appropriate analyses were conducted, task-specific patterns of results across the two object-types did not differ. Said another way, the patterns of results for the crucial interaction of barrier ×

compatibility was similar when comparing Simon-hand versus Simon-wooden block, as was the case for SRC-hand compared to SRC-wooden block, and finally for the hand and wooden block manipulations compared across the Stroop task. This is critical evidence in support of referential coding overall and moves in a direction against the hands, per se, as being the critical factor. Thus, this study implicates general referential objects as critical when spatial decisions (left or right responses) are to be made.

It may be that the hands are more logically represented to left- and-right presented stimuli, whereas artificial blocks more logically code to the outside versus the inside. Thus, when the judgments match the referent object – right/left to Simon and SRC; outside/inside to flanker and Stroop – this presents itself in the data as the largest reduction for the better-matched referent object. This difference leads to the possibility that there is unique hand processing above artificial block processing when only one hand or block is present in the visual array. This relation could be in a hierarchical level of importance in which the hands would rank higher than an artificial barrier for these conditions in terms of the impact on attentional focusing.

The results of this study make a significant contribution to the study of hands-related effects and further demonstrate the impact of a referential object across spatial compatibility tasks. The project is unique in that several choice-reaction tasks were studied under similar conditions in order to ascertain the extent to which a referential object does or does not impact performance. The goal of the project was to determine a potential mechanism of response selection in the presence of a referential object and the circumstances in which it benefits responding.

Because each of the tasks has unique properties with regard to responding under conditions of incompatibility between stimulus and response, we ascertain an understanding about the impact of referential objects in resolving irrelevant and conflicting information. Results from the Stroop task replicate the findings in prior literature (Davoli & Brockmole, 2012; Murchison & Proctor 2015 a, b), but also demonstrate that the artificial wooden block does not need to mimic a hand's contouring, which is a major finding of this study.

Also, the comparison between the SRC and Simon tasks suggests that the benefit is not restricted to situations in which the location of the stimulus is irrelevant to determining the correct response. In the SRC task, the location is an integral part of responding. Since the methodology was repeated between the SRC and Simon experiments, with that exception, the combined effects suggest some other mechanism. Additionally, the SRC task does not show a cost to responding on compatible trials, which further supports that the effects are due to location information no longer coming into play for responding. Thus, the hands and wooden blocks are eliminating part of the difficulty responding to incompatible/incongruent information both when the location information is relevant and irrelevant. Many accounts of compatibility effects advocate dual routes (Kornblum et al., 1990): one automatic (in this case for compatible trials based on location) and one intentional (for incompatible information based on instructions). These studies offer evidence that the activation of the automatic route is reduced, thus eliminating the conflict from that route. Consequentially, responding would be driven by the intentions one holds based on task context and instructions.

Thus, the overall strength of this combination of experiments is a greater understanding of the impact on attentional orienting from a referential object in translation and response selection processes. I include both of the processes common in information processing because the study demonstrates that both are affected: translation because the SRC tasks demonstrated, in a mapping task, reductions in interference due to the presence of a referential object; response selection because the Simon and Stroop tasks both had reductions in interference for analogous conditions for which a response is being selected amongst alternatives.

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APPENDICES

Appendix A

Mean RT and PE Data Broken Down Into all Factors Throughout Experiments 1-6

Table 1

Experiment 1: Simon Task With Hands

		Left				Right			
		RT (ms)		PE		RT (ms)		PE	
Barrier Location	Congruency	Palm	Back	Palm	Back	Palm	Back	Palm	Back
Between	Congruent	590	608	1.1	1.5	601	612	1.2	0.9
	Incongruent	611	623	1.1	1.7	619	621	1.1	0.9
Below	Congruent	588	596	1.1	1.1	599	593	1.7	1.5
	Incongruent	643	664	1.9	1.9	658	639	1.9	2.7

Table 2

Experiment 2: Simon Task With Wooden Blocks

Barrier Location	Congruency	RT (ms)	PE
Between	Congruent	594	1.2
	Incongruent	599	2.6
Below	Congruent	609	0.6
	Incongruent	621	2.2

Table 3

Experiment 3: SRC Task With Hands

		Left				Right			
		RT		PE		RT		PE	
Barrier Location	Compatibility	Palm	Back	Palm	Back	Palm	Back	Palm	Back
Between	Compatible	464	485	1	0.9	504	573	1	2.77
	Incompatible	567	536	1.4	4.3	514	536	2.3	0.3
Below	Compatible	442	486	1	0.9	494	549	1	2.6
	Incompatible	573	675	0.8	4.1	631	599	3.8	1.29547

Table 4

Experiment 4: SRC Task With Wooden Blocks

Barrier Location	Compatibility	RT (ms)	PE
Between	Compatible	606	1
	Incompatible	626	1.4
Below	Compatible	614	1
	Incompatible	647	1.4

Table 5

Experiment 5: Stroop Task With Hands

		RT		PE	
Barrier Location	Congruency	Palm	Back	Palm	Back
Between	Congruent	805	771	0.7	0.7
	Incongruent	829	806	2.0	2.6
Below	Congruent	820	884	1.0	1.9
	Incongruent	923	926	2.5	2.9

Table 6

Experiment 6: Stroop Task With Wooden Blocks

Barrier Location	Congruency	RT (ms)	PE
Between	Congruent	699	1.7
	Incongruent	732	2.8
Below	Congruent	698	2.3
	Incongruent	799	3.1

Appendix B

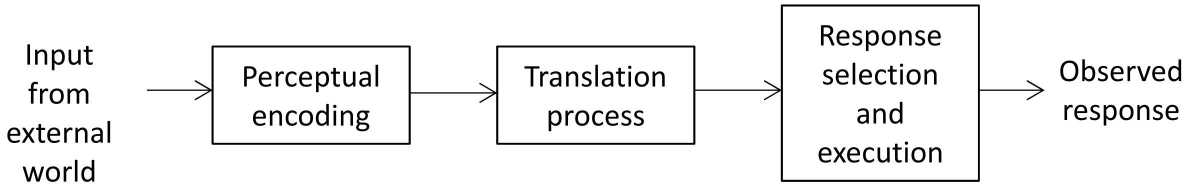


Figure 1. Three stages of information processing theory (Rabbitt, 1979, p. 145).

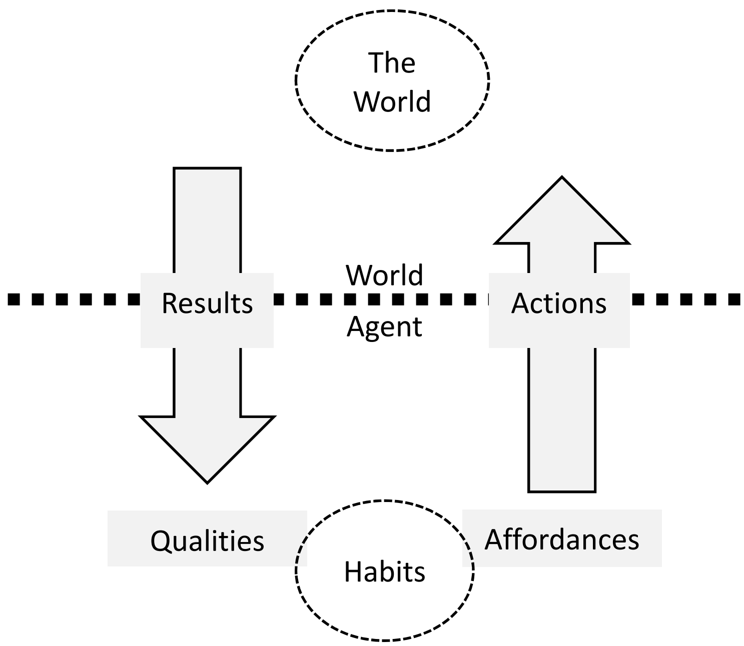


Figure 2. The classical drawing depicting ecological psychology (adapted fromGibson, 1979).

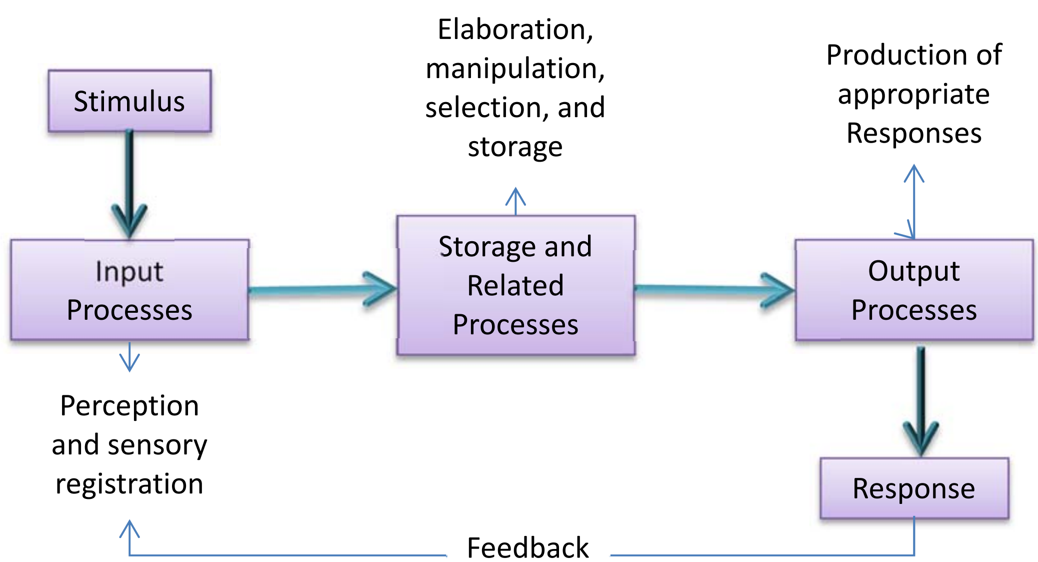


Figure 3. A classical drawing depicting information processing (adapted from Thadani, 2016).

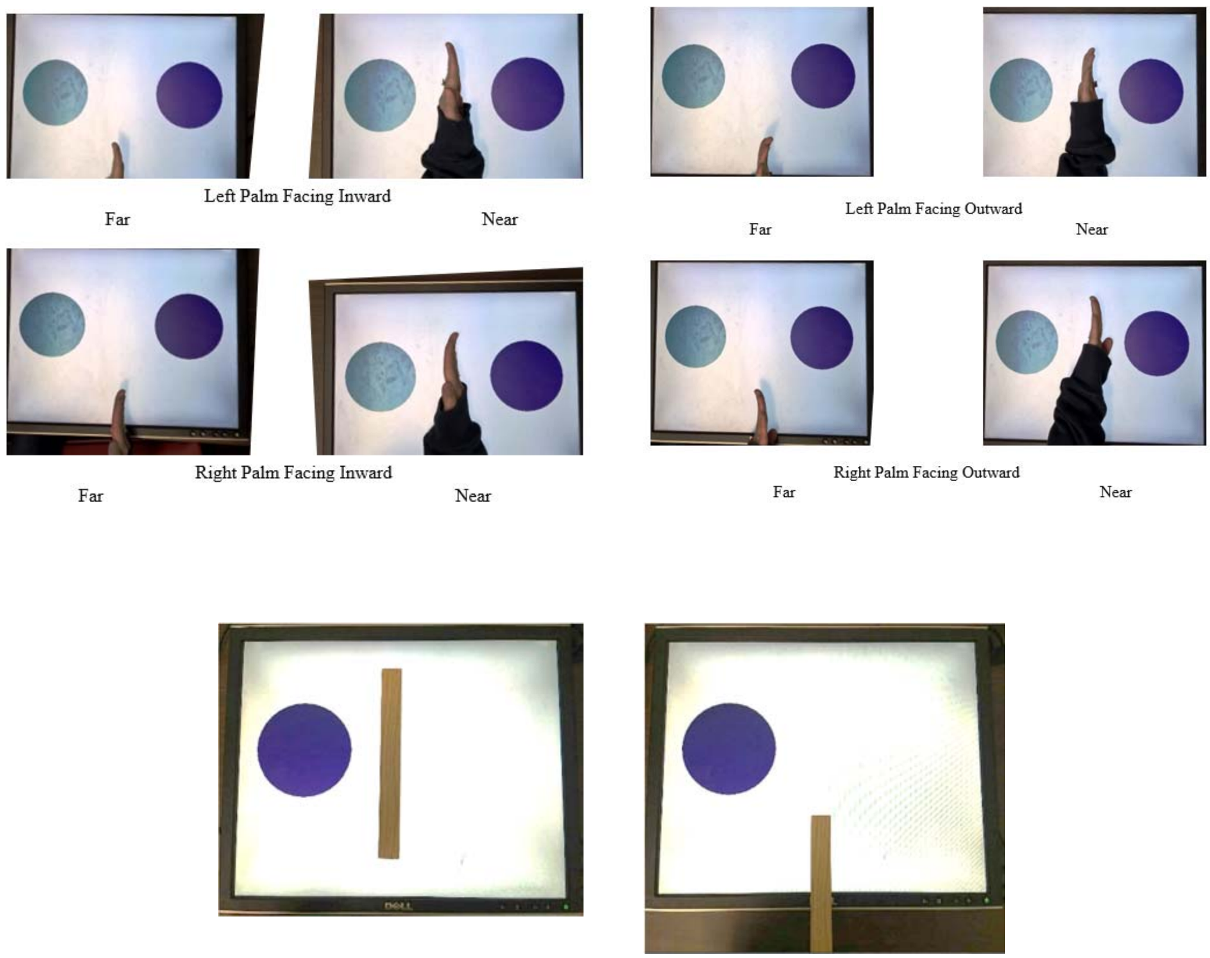
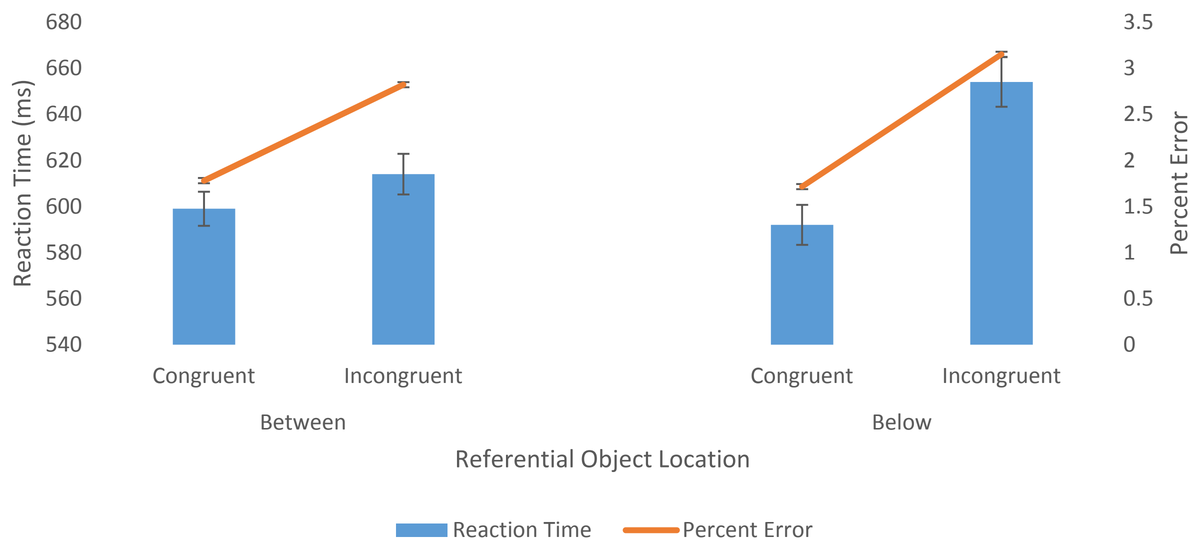


Figure 4. Hand postures for hands facing inward (upper left panel) and hands facing outward (upper right panel) and wooden block conditions (lower panel).

A



B

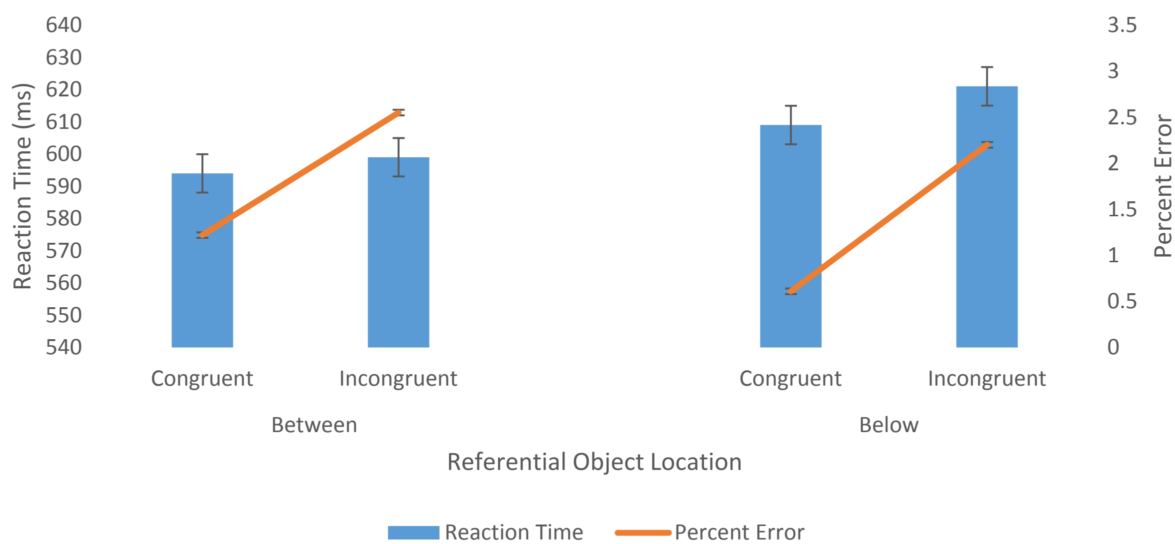


Figure 5. Experiments 1 and 2: RT and PE for congruent and incongruent trials with the barrier (hand or block) located between or below the stimuli: A) Hands as barriers; B) Wooden blocks as barriers. Bars designate RT (left axis); lines designate PE (right axis). Error bars represent ±1 standard error of the mean, computed using the method for within-subjects designs (Cousineau, 2005).

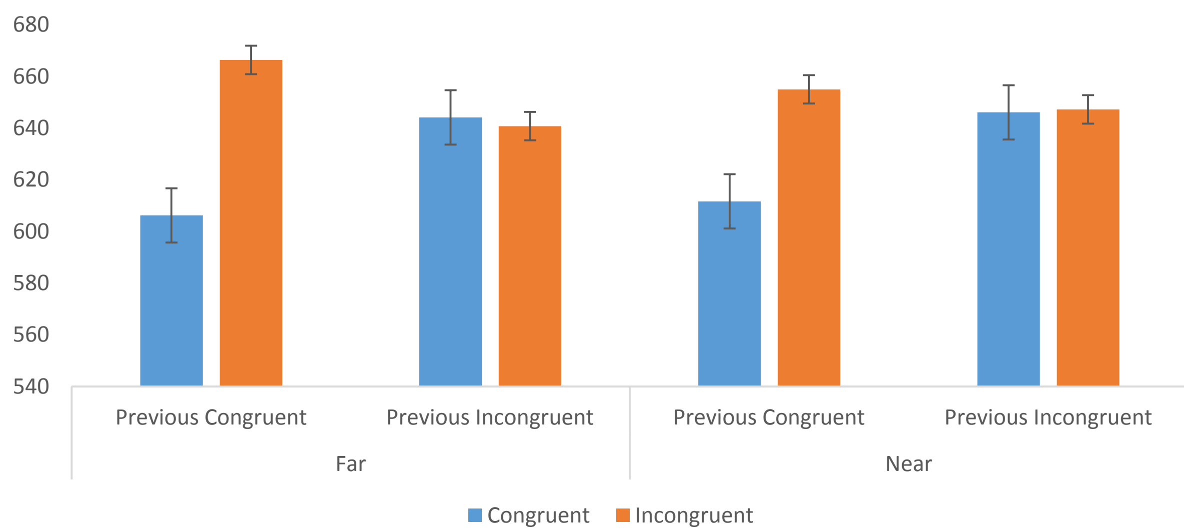
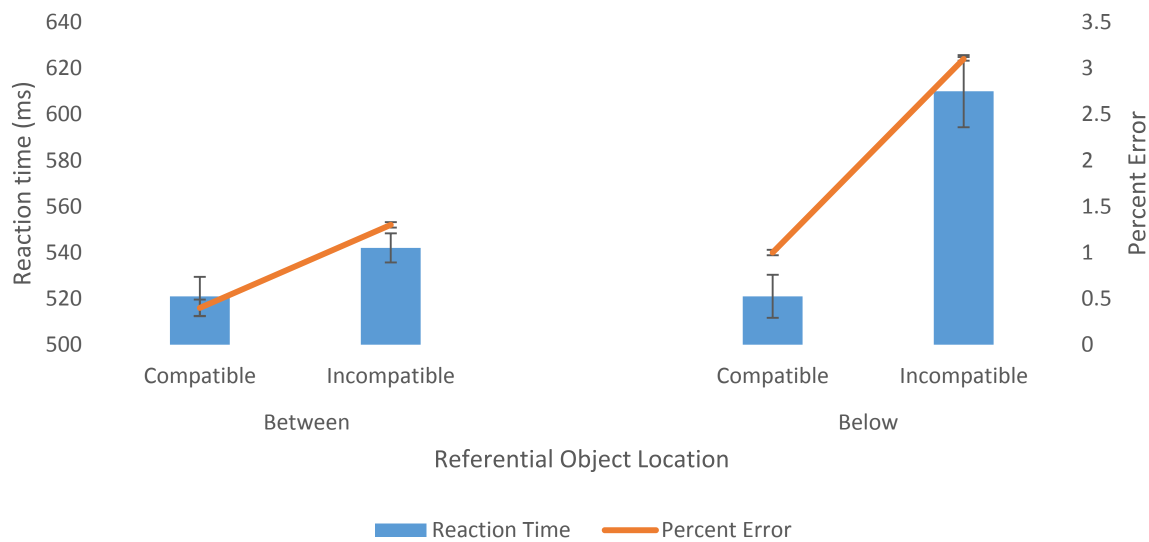


Figure 6. Sequential effects in the Simon task.

A



B

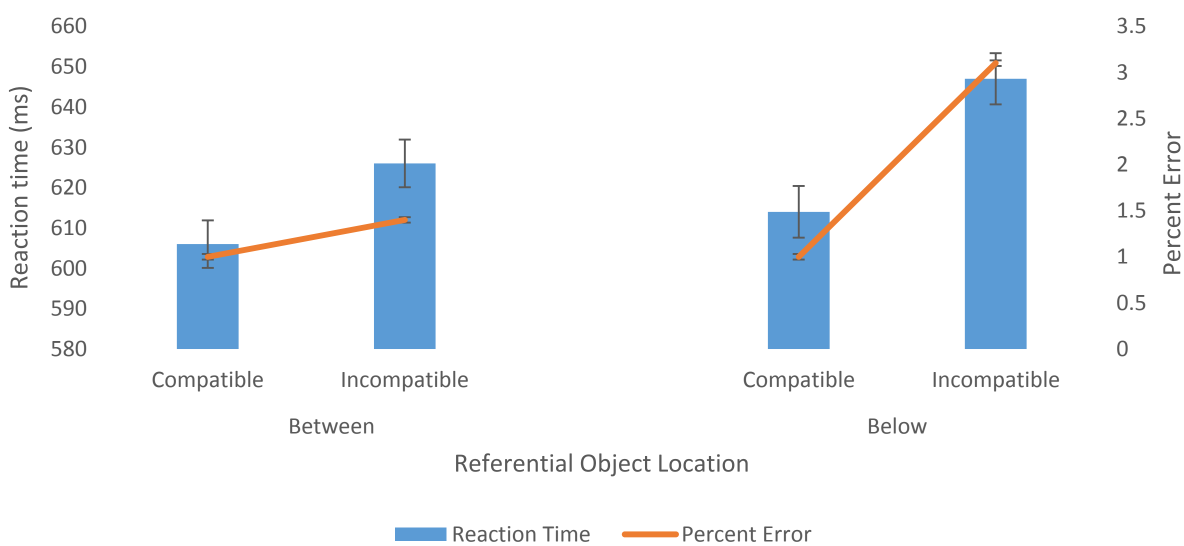
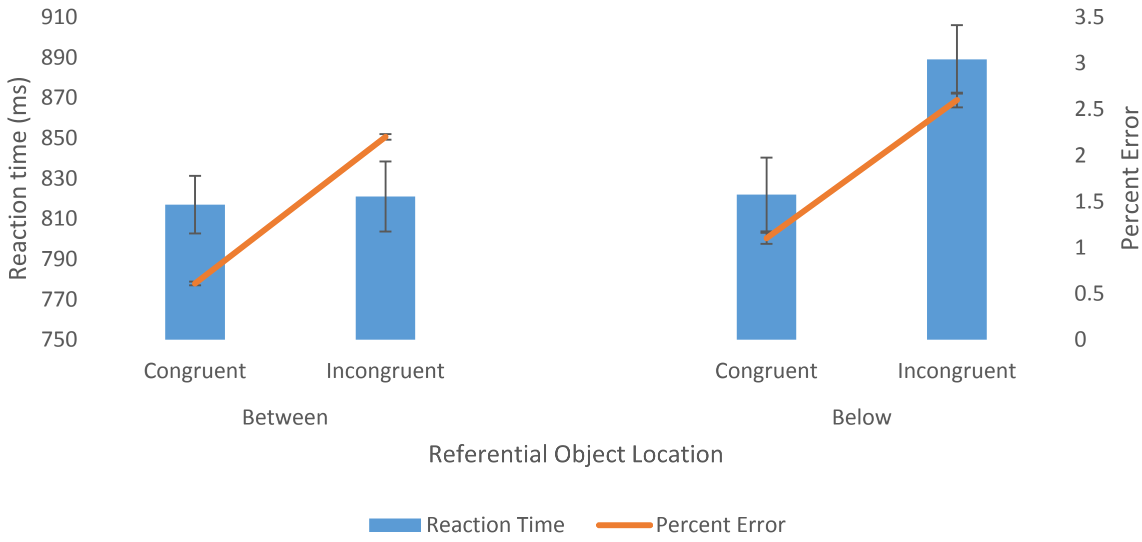


Figure 7. Experiments 3 and 4: RT and PE for congruent and incongruent trials with the barrier (hand or block) located between or below the stimuli in A) Hands as barriers and B) Wooden blocks as barriers. Error bars represent ±1 standard error of the mean, computed using the method for within-subjects designs (Cousineau, 2005).

A



B

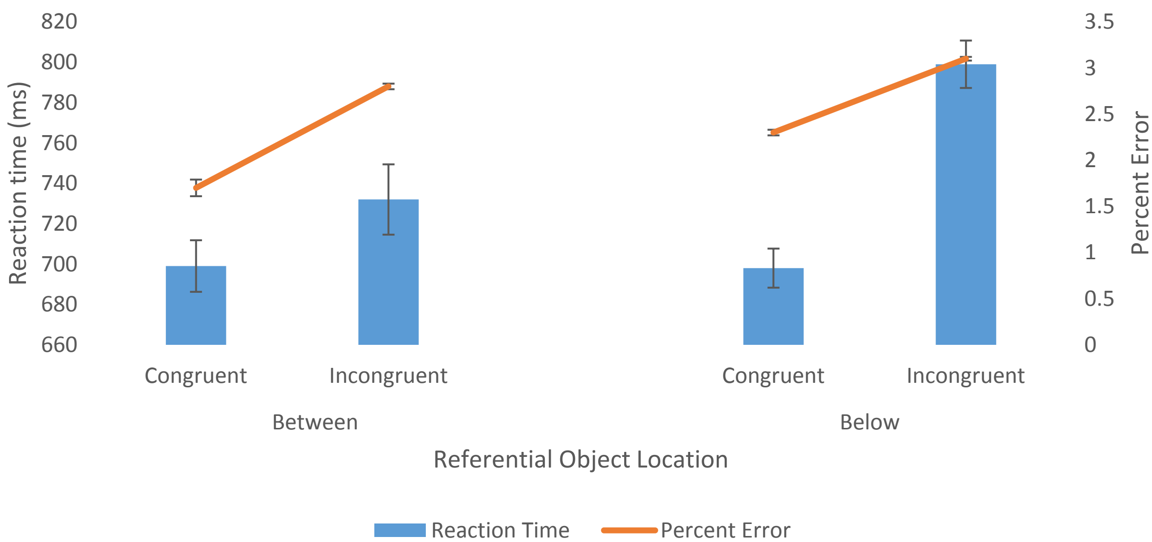


Figure 8. Experiments 5 and 6: RT and PE for congruent and incongruent trials with the barrier (hand or block) located between or below the stimuli in: A) Hands as barriers; and B) Wooden blocks as barriers. Error bars represent ±1 standard error of the mean, computed using the method for within-subjects designs (Cousineau, 2005).

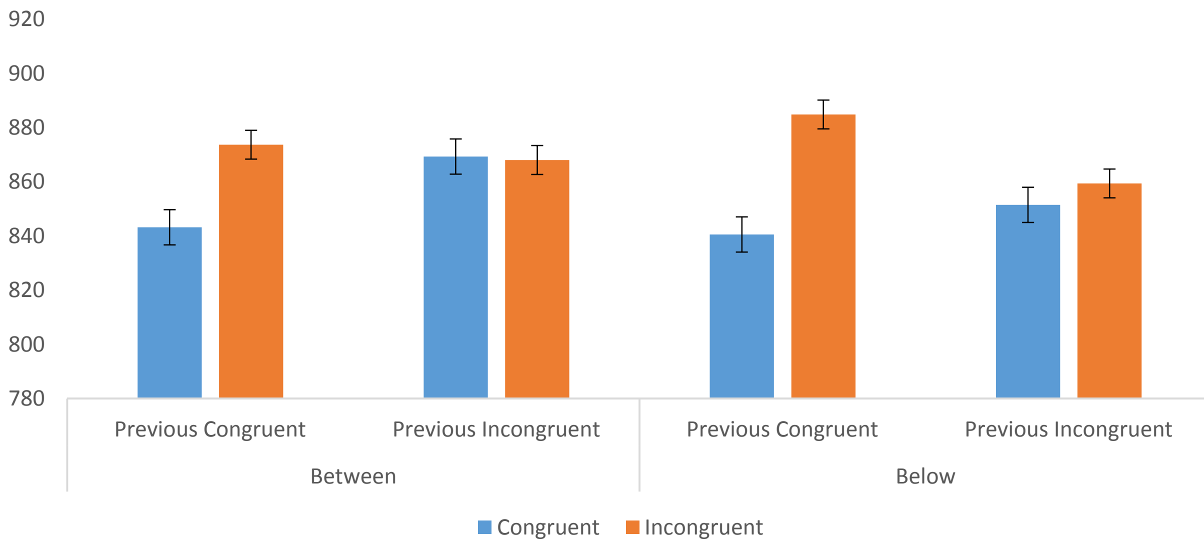


Figure 9. Sequential effects in the Stroop task.

VITA

VITA

Nicole M. Murchison

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SUMMARY

Passionate human factors professional with more than 7 years of progressive experience as a researcher at universities working with human subjects.

It is my goal to apply experimental, statistical, mathematical or other research techniques in the systematic investigation and study of the behavior, capacities, traits, interests, and activities of those persons within a system. I can provide the application of both human factors and psychological principles, theories, methods, and techniques to study and solve problems. I also am proficient at assisting and running statistical analyses.

Purdue University: Doctor of Philosophy (expected) – Psychological Sciences, cognitive psychology / human factors emphasis. Master of Science – Psychological Sciences. Master of Science – Industrial Engineering. Graduate Certificate – Psychological Statistics

Formerly at Colorado State University: Bachelor of Science with Honors – Psychology

PUBLICATIONS

Murchison, N. M., & Proctor, R. W. (2013). Spatial Compatibility Effects with Unimanual and Bimanual Wheel-Rotation Responses: An Homage to Guiard (1983). *Journal of Motor Behavior, 45,* 441-454.

Murchison, N. M., & Proctor, R. W. (2015). How Hand Placement Modulates Interference from Extraneous Stimuli. *Attention, Perception, and Psychophysics, 77,* 340-352.

Murchison, N. M., & Proctor, R. W. (2015). Intentional Control of Visual Attentional Resources Benefits from Referential Objects. *Psychonomic Bulletin & Review*, 1-6.

Murchison, N. M., & Proctor, R. W. (2015). The Skeptic's Perspective: A Critical Evaluation of Hand-Posture Effects in Attentional Research. *In Prep.*

Murchison, N. M., & Proctor, R. W. (2015). Effect of Hand Posture on Attentional Resources of Object Properties. *In Prep.*

EXPERIENCE

August 2010- May 2011	Teaching Assistant, Introductory Psychology Held exam review sessions, graded mini-writings, class administration.
August 2011- Present	Teaching Assistant, IE/PSY 577 – Human Factor in Engineering Responsible for grading, overseeing homework assignments, maintaining the online website, holding office hours, and lecturing when the professor was absent.
August 2011- Present	Research Assistants' Mentor – Taught undergraduate students a process for designing experiments, data collection, analysis, and interpretation.
January 2014- Present	Teaching Assistant, PSY200 -- Introductory Statistics Responsible for grading, overseeing homework assignments, holding office hours, created sheet to assist student studying.
August 2010- December 2010	Supervised College Teacher – Controversial Issues in Psychology Lead discussions, graded presentations, planed classroom activities, and solve problems within a classroom.

EDUCATION

August 2016 (expected)	Doctor of Philosophy – Psychological Sciences, Purdue University
May 2016	Graduate Certificate – Psychological Statistics, Purdue University
May 2016	Master of Science – Industrial Engineering, Purdue University
August 2013	Master of Science – Psychological Sciences, Purdue University
April 2011	Bachelor of Science – Psychology, Colorado State University

AFFILIATIONS

Human Factors and Ergonomics Society
Purdue Student Chapter:
Fall 2014 – President
2013-2014 – Vice-President and Secretary
2013 – Secretary
Rocky Mountain Psychological Society
American Psychological Association
Association for Psychological Science
Colorado State University Alumni Association